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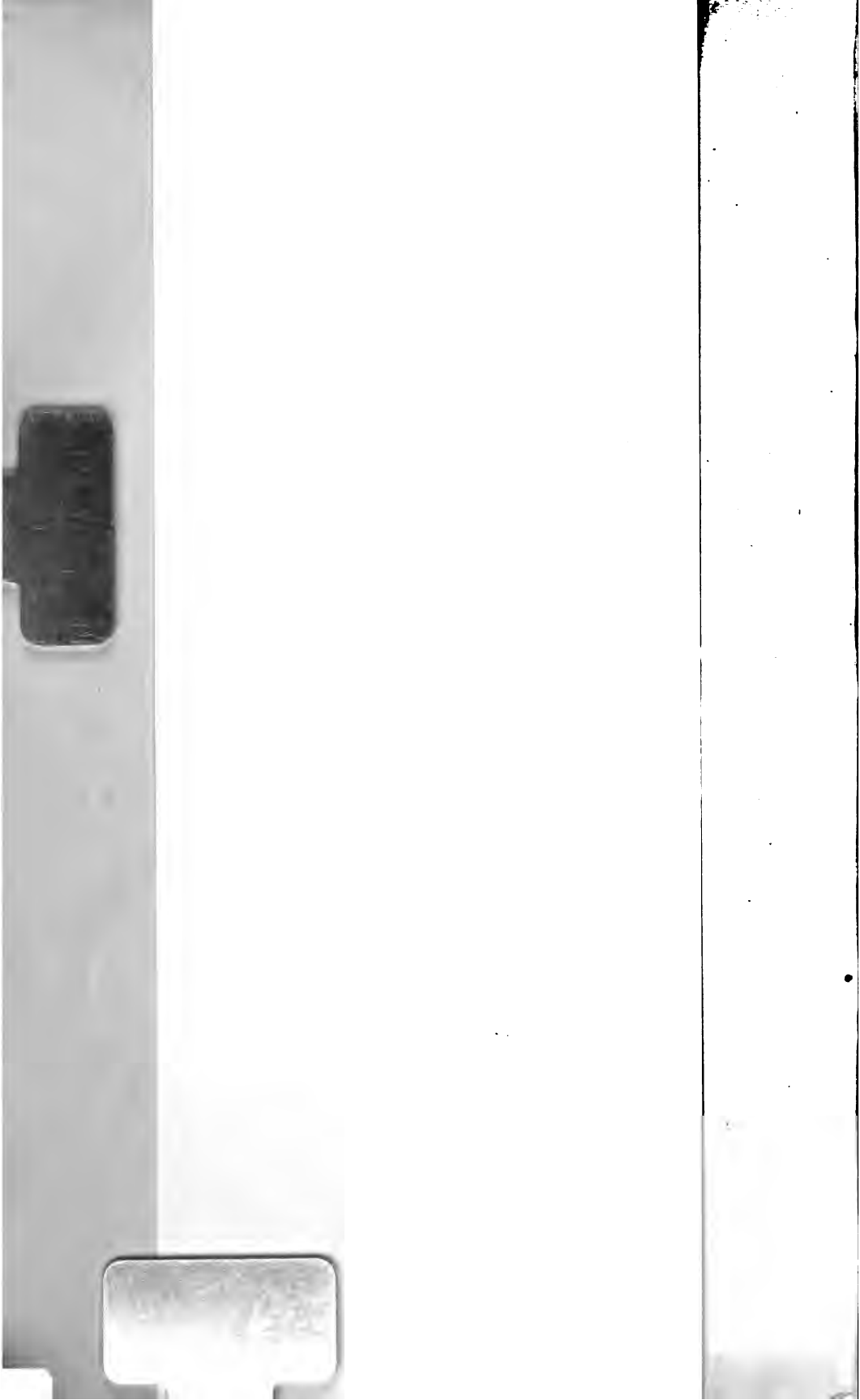

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PROPOSED PLAN

FOR A

SEWERAGE SYSTEM,

AND FOR THE DISPOSAL OF THE SEWAGE

OF THE

CITY OF PROVIDENCE.

BY

SAMUEL M. GRAY,

CITY ENGINEER.

MADE BY ORDER OF THE CITY COUNCIL OF THE CITY OF PROVIDENCE.

PROVIDENCE:

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of Boston.

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LETTER OF TRANSMITTAL.

To the Honorable the City Council of the City of Providence:

GENTLEMEN, — I have the honor to hand you herewith my report relating to a proposed system of intercepting sewers, and to the disposal of sewage.

In conformity to resolutions of the city council approved Feb. 23, 1884, accompanied by Mr. Charles H. Swan, I proceeded to Europe early in March. We were cordially received by the engineers and officials whom we met there, and are especially indebted to the following gentlemen for marked courtesy and much valuable information and advice: —

Sir Robert Rawlinson, C. B., M. Inst. C. E., etc., Chief Engineering Inspector Local Government Board, London.
Mr. James Forrest, Sec. Inst. Civil Engineers, London.
Mr. James Mansergh, M. Inst. C. E., London.
Mr. Baldwin Latham, M. Inst. C. E., London.
Mr. J. C. Melliss, Assoc. M. Inst. C. E., London.
Mr. J. Gordon, M. Inst. C. E., Borough Engineer, Leicester.
M. Ernest Pontzen, C. E., etc., Paris.
M. A. Durand-Claye, Ingenieur en Chef des Ponts et Chaussées, etc., Paris.
M. Humblot, Ingenieur en Chef, etc., Paris.
Mr. Alexander Aird, Assoc. M. Inst. C. E., Berlin.
Oberbaurath James Hobrecht, Berlin.
Geheimrath E. Wiebe, Berlin.
Mr. Thomas Airey, Assoc. M. Inst. C. E., Breslau.
Mr. Peter Collas, U. S. Vice-Consul, Dantzic.
Herr H. Dodenhoeft, Dantzic.
Herr Herman Augstein, Civil Ingenieur, Dantzic.
Mr. Wm. H. Lindley, M. Inst. C. E., Frankfort-on-the-Main.
Herr B. Loehr, Ingenieur, etc., Frankfort-on-the-Main.
Inspector Hoseus, etc., Kuranstalt, Falkenstein, Cronberg, Taunus.
Mr. John Grant, M. Inst. C. E., London.

Mr. Thomas Lovick, C. E., London.
Mr. W. Stevens, Sec. Native Guano Co., London.
Mr. W. C. Sillar, Patentee of A. B. C. process, London.
Mr. John Lund, C. E., Town Surveyor, Bedford.
Mr. W. Roff, Bedford.
Mr. W. S. Till, M. Inst. C. E., Borough Engineer, Birmingham.
Mr. Alexander R. Binnie, M. Inst. C. E., Bradford, Yorkshire.
Mr. Webster, City Hall, Bradford, Yorkshire.
Mr. Thomas Craig, Bradford, Yorkshire.
Mr. J. E. Stafford, C. E., Borough Surveyor, Burnley.
Mr. T. N. Dall, Deputy Borough Surveyor, Burnley.
Mr. H. U. McKie, Assoc. M. Inst. C. E., City Surveyor, Carlisle.
Mr. B. S. Brundell, M. Inst. C. E., Doncaster.
Mr. R. S. Brundell, Assoc. M. Inst. C. E., Doncaster.
The Borough Engineer, Edinburgh.
Dr. Russell, Sanitary Dept., Glasgow.
Mr. Thomas Hewson, M. Inst. C. E., Borough Engineer, Leeds.
Mr. John Allison, Assoc. M. Inst. C. E., Borough Surveyor, Manchester.
Mr. W. H. White, M. Inst. C. E., Borough Surveyor, Oxford.
Mr. W. Santo Crimp, Assoc. M. Inst. C. E., etc., Surveyor Local Board, Wimbledon.
Mr. C. H. Cooper, Assoc. M. Inst. C. E., Wimbledon.
Lieut. Col. Alfred S. Jones, V. C., Wrexham, Wales.
Mr. Isaac Shone, Assoc. M. Inst. C. E., Wrexham, Wales.
M. J. B. Berlier, C. E., etc., Paris.
Capt. Charles T. Liernur, Amsterdam.
C. M. de Bruijn Kops, C. E., Amsterdam.
Signor Emilio Bignami Sormani, Ingegnere, Milan.

We also wish to acknowledge the attention received from superintendents and managers of sewage works, among whom may be mentioned: —

Mr. Thomas Allen, Manager Sewage Works, Merton, England.
Mr. R. Cattell, Manager Sewage Works, Leyton, England.
Mr. E. F. Coddington, Manager Sewage Works, Coventry, England.
Mr. I. Cramp, Manager Sewage Works, Hertford, England.
Mr. E. H. Hawkes, Manager Sewage Farm, Warwick, England.
Mr. Kilpatrick, Sanitary Works, Manchester, England.
Mr. A. Marriage, Manager Croydon Sewage Farm, Mitcham, England.
Mr. James Milne, Engineer, Pumping Station, Oxford, England.
Mr. Paige, Manager Sewage Works, Aylesbury, England.
Mr. Richardson, Manager Sewage Works, Leeds, England.
Mr. David Tough, Manager Sewage Farm, Leamington, England.
Mr. John Wilkinson, Supt. Interception Dept., Birmingham, England.

I take pleasure in availing myself of this opportunity of expressing my obligations to many persons who have rendered me assistance in the preparation of this report.

I wish to express my thanks to his Honor Thomas A. Doyle, Mayor. While abroad his official letters were of great service to us in making the investigations recommended in his inaugural address.

I desire to recognize the value of the services of Mr. Charles H. Swan, whose previous acquaintance with the ground over which we travelled, and knowledge of the subject of town sanitation and its literature, formed a useful preparation for the journey, and contributed largely to the success of our visit abroad. I wish to recognize, also, the value of his services in the preparation of Appendix A.

I am also indebted to Mr. Otis F. Clapp, assistant engineer in charge of the sewer department, for services rendered in conducting many surveys, as well as making estimates and plans, and compiling much information required in this work.

I take this occasion to express my thanks to John Howard Appleton, Professor of Chemistry of Brown University. I have considered myself fortunate in being able to secure from time to time the benefit of his professional services.

I tender my thanks to Dr. E. M. Snow, city registrar, and to Dr. C. V. Chapin, superintendent of health, for their official co-operation in this work.

I am also indebted to Mr. Rudolph Hering, C. E., of Philadelphia, for valuable professional advice.

Respectfully,

SAMUEL M. GRAY,
City Engineer.

PROVIDENCE, R. I., Nov. 14, 1884.

REPORT.

CITY ENGINEER'S OFFICE, CITY HALL,
PROVIDENCE R. I., July 23, 1884.

To the Honorable the City Council of the City of Providence:

In pursuance of certain resolutions passed by your honorable body, to wit: —

Resolved, That the city engineer is hereby directed to report plans of the main intercepting sewers, and of any other work necessary for collecting, conducting, and disposing of the sewage of the city in accordance with the best approved methods at such a point and in such a manner as will be the least injurious to the public health, together with estimated cost thereof. (Approved Sept. 15, 1882.)

Resolved, That the city engineer and assistant Charles H. Swan be, and they are hereby, directed to proceed to Europe to investigate the various plans in practical operation for the disposition and utilization of sewage, together with all matters relating thereto, and the city engineer shall report to the city council the result of such investigations with such recommendations with reference to the sewage of this city as he may deem expedient, said report to be made in print on or before the second Monday in September ensuing, (Approved Feb. 23, 1884.)

I respectfully present the following report: —

During these investigations, sewerage systems and methods for the disposal of sewage have been inspected at the following places: —

The pail system of disposing of excreta at Birmingham and Manchester, England.

The Liernur system of sewerage at Amsterdam.

The Berlier system at Paris.

The Shone system at Wrexham, Wales.

The combined system at London, Berlin, Paris, and Frankfort-on-the-Main.

The separate system at Oxford, and at Paris where it is being tried experimentally to a limited extent.

Works for the disposal of sewage by irrigation were inspected at the following places: Bedford, Berlin, Breslau, Croydon,

Dantzic, Doncaster, Edinburgh, Leamington, Milan, Oxford, Paris, Warwick, Wimbledon, and Wrexham.

Works for the disposal of sewage by chemical precipitation were inspected at the following places: Aylesbury, Birmingham, Bradford, Burnley, Coventry, Cronberg, Hertford, Leeds, and Leyton. Works in process of construction were also seen at Frankfort-on-the-Main.

Recommendations. As the result of my investigations and study of this question, I recommend, first, that intercepting sewers be built; second, that the sewage of the city be conveyed to Field's Point; third, that it be treated there by chemicals in such a manner as to precipitate the matters in suspension and to clarify the sewage; fourth, that the clarified effluent be emptied into deep water at Field's Point.

My reason for recommending precipitation is that I am confident that the sewage can be so clarified that the effluent will be entirely harmless when emptied into the river at Field's Point, and the purification can be accomplished at less expense than by irrigation. Although sewage is more fully purified by irrigation than by precipitation, I have not felt justified in recommending its adoption, for, from careful and extended surveys, I am convinced that the large amount of suitable land required for irrigation cannot be obtained at any reasonable cost within reasonable distance of the city.

Intercepting Sewers. In order to intercept and take the sewage to Field's Point, I recommend the adoption of the system of intercepting sewers described in Appendix C, pages 126–132, and shown by heavy lines on general plan of city in Appendix C. It is not necessary to construct at present all the sewers therein described, but only such as are necessary to intercept sewage which would otherwise enter the rivers. It will be seen by the plan of the ninth ward, in Appendix C, that the main sewer from this ward meets the marginal sewer coming down Allen's Avenue near the cove known as Corliss Cove.

Pumping Station. At a point marked "A," it is proposed to erect pumping works. The sewage from a part of the eighth ward and from most of the ninth will not require pumping. The sewage from the remainder of the

city will be lifted about twenty-eight feet into a conduit through which this sewage, together with that from the eighth and ninth wards already referred to, will flow to the precipitation works, to be located at a point marked "B."

Precipitation Works. At this point B it is proposed to construct tanks and erect suitable buildings and works for the mixing of chemicals with the sewage, and for the handling of the sludge, etc. The sewage, after receiving the mixture of chemicals, will flow into precipitation tanks, where it will remain for a short time to cause the deposit of sludge; the clarified effluent will flow off into deep water at the point as shown on the plan.

Sludge. The sludge left in the bottom of the tanks will then pass into receivers, from which it will be forced by compressed air into filter presses. Plate 23 in Appendix A represents such a press. By this press the sludge is easily compressed into a portable form. That this sludge possesses some value as a fertilizer there is no doubt; it remains to be proved whether there will be any sale for it in this vicinity. Therefore, for the purposes of this report, I assume that there will be no immediate income from its sale as a fertilizer.

Floats. Extensive experiments have been made with floats at different points in Providence River, principally at Field's Point and at Conimicut Point, to ascertain what probable action the tide and the currents of the river would have on the sewage if emptied at these points. A description of the experiments and the floats will be found in Appendix C, pages 133 to 135. These floats were put in at high tide. As will be seen by reference to the charts in the Appendix, many of these floats, after having been carried down by the outgoing tide, were brought back by the incoming tide towards, and (in some cases contrary to expectation) above, the point at which they were started.

Pollution of Rivers. From a careful study of these experiments, and from a long and close observation of the causes of the present pollution of the Cove, the Providence River and its tributaries, I am of the opinion that if the crude sewage of the city be emptied into the river at Field's Point it will inevitably cause a nuisance, to the injury not only of the

dwellers within the city, but to the occupants of many of the shore resorts and residences bordering on the Providence River and Narragansett Bay, and will seriously damage, if not destroy, many of the valuable oyster beds which now line the shores. I call your attention to letters upon this subject from Professor John Howard Appleton, of Brown University, and from Dr. C. V. Chapin, Superintendent of Health, found in Appendix C, pp. 140–146. The high standing of these gentlemen in their professions renders their views of great weight. A very important factor in the pollution of the Cove, as well as the Providence River and its tributaries, is the liquid wastes of manufactories emptied into the rivers. There are, as near as I can estimate from the best obtainable data, upwards of 2,735,000 gallons of filthy liquid wastes emptied daily (Sundays excepted) into the Moshassuck and West Rivers, and upwards of 2,088,000 gallons into the Woonasquatucket River, making a total of 4,823,000 gallons of filthy liquids, aside from town sewage, emptied into the several rivers during twelve or fourteen hours out of the twenty-four. I wish to call your attention emphatically to the fact that however thoroughly the town sewage may be kept from the rivers, if these foul liquids from manufactories are allowed to enter the streams, as at present, the Cove, together with the Providence River and its tributaries, will continue to present about the same filthy appearance that they do to-day. It is only by keeping all sewage and filthy liquids out of these waters, or by clarifying them before they are permitted to enter, and by thoroughly clearing the river beds from all deposits of filth, that we may look for improvement in the condition of the Providence River and its tributaries. I am convinced from my observations abroad, that in some cases the quantity of liquid wastes now emptied into the rivers from manufactories might be materially reduced, and that the remainder could be so clarified by the proprietors as to prevent polluting the river, and possibly result in some instances in a source of income to them.

Manufactories' wastes.

In designing the sizes of the intercepting sewers, I have thought best to make provisions for receiving the liquid wastes of these manufactories. It is an important question for your consideration on what

conditions it may be advisable to admit these liquid wastes into the sewers.

Quantity of Sewage. The estimated daily dry-weather flow of town sewage in Providence at the present time is about 3,000,000 gallons. This is based on careful and extensive gaugings made at different times of the amount of sewage flowing in the several sewers. A clearer idea of the extent of these gaugings will be gained by reference to diagrams and table of gaugings found in Appendix C, pages 136 and 137. It will be seen by table of gaugings that the sewers laid in wet localities furnish a much greater quantity of sewage, per inhabitant connected, than do the sewers laid in dryer parts of the city. This larger quantity of sewage is due in most localities to spring or ground water, which finds its way into the sewer. The great value to the general health of the community of thus draining the ground is too apparent to need comment. As will be seen by Appendix C, page 138, there were, on June 1, 1884, 3,528 connections with the sewers. It is estimated that these connections take the sewage from 36,421 inhabitants.

Population provided for. In designing the intercepting sewers, liberal provision has been made for a population of 300,000 inhabitants within the present city limits, together with small districts lying outside the present limits, whose only outlet will be through the city. (Referred to in Appendix C, pages 128, 131.)

Sizes of Sewers. The intercepting sewers (excepting the main sewer of the ninth ward) are designed to carry $\frac{1}{100}$ of an inch of rain-water per hour from the district drained, together with the liquid wastes before referred to from manufactories, and sixty gallons of sewage per inhabitant, including ground water. The manufactories' waste is estimated to flow off in ten hours; of the sewage, one half is estimated to flow off in seven hours. This requires a marginal sewer, when flowing nearly full, of seven feet two inches diameter at the lower end in Allen's Avenue, near the Corliss Cove.

At the junctions of the district outlet sewers with the intercepting sewers, there will be overflows into the river for the

relief of the sewers from the excess of rain-water. These overflows will be so arranged that when the amount of rain-water coming from the district sewers exceeds the amount provided for in the intercepting sewer, the excess of water will flow directly into the river. An overflow will also be provided near Field's Point, to be used, if necessary, in case of heavy storms.

Much study has been given to the question of draining the ninth ward. The flatness of this territory, the long valleys and the absence of streams necessary to receive overflow, render it desirable to provide for more surface water than in other parts of the city, where overflows can be easily and safely made. In consideration of these facts, in making the estimates of cost of sewer for this district, I have provided for a two-inch rainfall on this territory, in addition to the sewage.

There will be an overflow from this ninth-ward sewer into the Cove near the proposed pumping station.

Marginal Sewers. The marginal sewers should be so constructed that no spring or ground water will leach into them, thereby reserving their whole capacity for the purposes for which they are built.

Sewage from area above and below contour of 25. The drainage (aside from the portion provided for by overflows) which comes from that part of the city lying below the contour of about twenty-five will of necessity require pumping. The drainage coming from the territory above that contour may be intercepted and conveyed by an independent or separate sewer to Field's Point and discharged by gravity.

The quantity of sewage now coming from this higher territory (not including the ninth ward already spoken of) is not enough to warrant the expense of constructing this independent sewer at the present time, as the interest on the outlay for it would very much exceed the cost of pumping the present flow of sewage from this district. Provision is however made, in the system proposed, for the construction of this independent sewer when the proper time arrives.

Systems. The system of sewerage in use in this city, as is generally known, is the combined system.

Of the sewers now laid (about fifty miles) very

few, if any, need be disturbed, and usually in the future it will be well to continue the combined system, except in special cases where the separate system may be used to better advantage, or where storm-sewers may be needed.

Estimated Cost. The estimated cost of the whole work herein recommended is $3,699,504.00.

In estimating the cost of the precipitation tanks and pumping machinery, liberal provision has been made for present needs; that is, for the amount of sewage that may be intercepted on the completion of such marginal sewers as are needed at present. The tanks and machinery are to be so arranged that additions can be easily made when required. In all other respects the estimate includes the whole cost of the complete system of marginal and outfall sewers needed for a population of 300,000 inhabitants.

A more detailed statement of estimates will be found in Appendix C, page 139.

Cost of Chemicals, Labor, etc. Experience in England, on well-managed works, shows that the cost of chemicals and labor for treating sewage by precipitation varies from 1 shilling (24 cents) to 1 shilling 6 pence (36 cents) per annum per inhabitant connected with the sewers. This cost would not form a safe basis upon which to calculate in this country. It is believed, however, that double the cost mentioned would be a liberal amount on which to base our estimates of the cost of the chemical precipitation of sewage.

Suggestions. In this connection it may not be improper to consider some of the various suggestions that have been made for disposing of the sewage of this city by irrigation and otherwise.

Experience indicates that the amount of land required for the disposal of sewage by irrigation is about one acre to one hundred inhabitants. The population provided for in the proposed system of intercepting sewers is 300,000. The amount of land necessary to properly dispose of the sewage of that population would be about 3,000 acres.

It has been suggested to take the sewage to Seekonk Plains for irrigation. The great expense of conveying the sewage

across the Seekonk River and to this land, together with the fact that the available area is less than one thousand acres, forbids a consideration of this scheme.

It has also been suggested that the sewage be taken to Warwick Plains and there used for irrigation. From extensive surveys of this territory, I am satisfied that there is not a sufficient quantity of suitable land in that locality for the future needs of the city. The estimated cost for construction, in accordance with this suggested scheme, including only sufficient quantity of land for the present needs, is $1,146,000 more than for the plan of precipitation herein recommended. The annual cost of pumping the sewage to Warwick Plains would be double the cost of the pumping required in the plan recommended. Considering the additional cost, and in view of the fact that there is not a sufficient quantity of land at Warwick Plains for future needs, I deem it unnecessary to further consider this scheme.

By combining precipitation with irrigation a much smaller area of land is requisite, and should it hereafter be deemed advisable to adopt some system of irrigation, the proposed precipitation works will form a most useful auxiliary.

Another suggestion has been made, which is to take the sewage down the river to Conimicut Point, and there, in its crude state, discharge it into the bay. I estimate that the carrying out of this scheme would cost $1,194,000 more than the plan I have recommended. The annual cost of pumping to Conimicut Point would be nearly double the cost of pumping in accordance with the plan recommended. Moreover, the experiments made at this point with floats show that there are strong reasons for fearing that crude sewage emptied into the bay at this point would create a nuisance in the not distant future.

Appendix A. Appendix A contains descriptions of the various systems of sewerage now in use in England and on the Continent of Europe, types of which I have carefully inspected. It also explains the general principles of sewerage and of sewage disposal, and gives much historical matter connected with the subject of town sanitation.

Appendix B Statistics. In Appendix B will be found tables of statistics obtained at places visited, and also statistics of the town of Pullman, Ill., which were kindly furnished by Col. W. E. Barrows.

Appendix C. Appendix C contains descriptions of location of marginal and main sewer lines, charts and explanations of float experiments, table and diagrams of gaugings of sewers, sewer district maps, and estimates connected with the proposed system for the city of Providence.

Concluding Statements. No system of sewerage is complete which fails to dispose of the sewage so as to avoid its causing a nuisance. It is believed that if the scheme herein recommended be thoroughly carried out, the Providence River and its tributaries may be reclaimed from their present filthy condition, and that the air which is now so often laden with foul gases rising from their waters may be preserved pure and wholesome.

While the cost of carrying out the plan herein recommended is large, aside from the annual expense for operation, and while no direct money returns can be expected to result from it, it cannot be denied that the gain in health and comfort that will result to our citizens will add prosperity and wealth to the city.

The time required for the completion of the work depends, of course, upon the vigor with which it is carried on. With such a force as could be employed to advantage, some portions of the work may be made available for use within two years; an additional year would suffice for its substantial completion.

Inasmuch as the resolutions under which this report is made call mainly for investigations relative to the disposal of sewage, I have omitted to dwell upon many other important questions relative to the subject of sewerage. Reference to some of them, however, is made in Appendix A.

The system herein recommended is not new, the constructions involved are not experimental; they are in successful operation in many of the towns and cities of Europe. Hence my confidence in recommending their adoption for the city of Providence.

SAMUEL M. GRAY,
City Engineer.

APPENDIX A.

SEWERAGE SYSTEMS AND SEWAGE DISPOSAL.

HISTORY OF TOWN SANITATION.

THE protection of the public health by means of the proper removal and disposal of household and town wastes is becoming a question of the first importance in this country. It has occupied the attention of the leading medical and engineering authorities in Europe for many years, especially in England, where the density of population and the great number of manufacturing establishments have caused the rivers and streams to be polluted to an extraordinary degree with liquid filth, and their channels to be encroached upon by deposits of offensive mud and heaps of solid refuse.

SANITATION IN ANCIENT TIMES.

The amount of attention given to the general subject of public health has been very various at different periods, and may be taken, to a certain extent, as an indication of the degree of civilization attained by different nations in the past.

The record of the sanitary works of the earlier nations of antiquity is very imperfect. The remains of works of sewerage and water supply have been discovered at nearly every place of importance where excavations have been made, both in the great cities, as Nineveh, Jerusalem, Carthage, and Rome, and in those of smaller size, as Pompeii, Herculaneum, and many other places.

Rome stands pre-eminent for the magnitude of its works of water supply and drainage. For more than four hundred years after the building of the city, the Romans were satisfied with water drawn from the Tiber, or from wells and springs. About the year 311 B. C., the first aqueduct for the general supply of the city was constructed. This, the Aqua Appia, was built by

Appius Claudius, and was about ten miles in length. Other aqueducts were constructed from time to time, as the growth of the city required.

At the time of the Emperor Claudius, about A. D. 52, Rome was being supplied with water by nine different aqueducts. The two longest, the Aqua Claudia and the Anio Nova, were fifty-eight and sixty-two miles in length, respectively. These aqueducts were all extremely massive and elaborate in construction. The water was conducted in masonry channels, supported for the greater part of the distance upon arches, some of which were more than one hundred feet in height. They were adorned with columns and other architectural ornamentations, and their ruins, together with those that remain in use at the present time, form a distinctive feature of the Campagna.

In Rome, every house was provided with a fountain, or water-tap, and a dwelling was not considered fit for occupancy, even for the poorest class, unless it was furnished with an abundant supply of water.

Among the public works of ancient Rome are mentioned eleven Thermæ, or public baths, eight hundred and fifty-six bath-rooms, and one thousand three hundred and fifty-two fountains for public use, in the streets.

Water, so bountifully supplied in ancient Rome, was used freely for all purposes. The practice of frequent bathing became universal, and the magnificent public bathing establishments, or Thermæ, erected under the emperors, are indicative of the extent to which luxurious habits had permeated all classes of Roman society. They covered acres of ground, and, besides the arrangements required for bathing, contained refreshment saloons, reading and conversational rooms, concert halls, theatres, and race-courses. They were ornamented with the most costly paintings, mosaics, and statuary.

The Thermæ of Diocletian were begun about A. D. 302. They were about six thousand feet in circuit, and the daily number of bathers is estimated at three thousand. The Thermæ of Caracalla were begun about A. D. 212. The establishment was quadrangular in form, surrounded by a wall. Its length and

breadth are stated to have been one thousand feet, forming a circuit of about four thousand feet. The magnificence of the establishment was unparalleled. The accommodations were sufficient for the wants of one thousand six hundred bathers at once.

The works for the sewerage of Rome were equal in magnitude to those for its water supply, but, being underground and destitute of architectural beauty, they have not left imposing ruins, as have the aqueducts.

The Roman sewers have passed into oblivion as a system. Ancient sewers are discovered from time to time, and are now frequently used, but it is seldom known where they lead.

The most notable example of the ancient sewers, the Cloaca Maxima, or main outfall sewer of Rome, was built by Tarquinius Priscus about six hundred years B. C. It is the earliest known application of the arch principle in Rome, and has defied the vicissitudes of more than two thousand four hundred years. It is still used for the purpose for which it was built. It is about fourteen feet in width and thirty-two feet in height. The arch which covers it is semicircular, and formed of three concentric rings of stone called peperino, laid without cement.

On examining the ruins of the various buildings, we find admirable and ample provision for their drainage, and, what is of far more importance, a dimension given to the sewers sufficient to render them effective. Their sectional area was increased as they advanced, and there appears to have been in Rome one general direction which proportioned the parts as well as the whole.*

Not only in the imperial city, but in every province of the Empire, the Romans constructed works of great magnitude for water supply and sewerage, as many ruins of Roman works in Italy, Spain, France, Germany, and England still testify.

DECLINE OF SANITARY SCIENCE IN THE MIDDLE AGES.

During the wars and political disturbances that followed the fall of the Roman Empire, public works of all kinds were neglected and allowed to pass into decay.

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* Cresy, Ency. Civ. Eng.

With increasing ignorance and poverty, sanitary precautions were disregarded, and slovenly and filthy habits prevailed. The doctrines of asceticism and of corporeal mortification, promulgated at this period, were carried to the extreme of physical endurance by their votaries. Cleanliness of person was looked upon as an evidence of a wicked and self-indulgent life; the practice of bathing was abandoned; clothing was worn without change until it decayed upon the person; filth was permitted to accumulate in the houses and streets until the latter were full of reeking abominations. The water supply, which was mainly obtained from wells, was, in time, so polluted by the foul saturation of the soil as to be absolutely unfit for use.

A terrible retribution followed this defiance of natural laws. History records the repeated devastation of Europe by epidemics during this period. The "Great Mortality," or "Black Death," which prevailed from A. D. 1347 to 1350, originating in the far East, approached through Asia Minor and Egypt, and ravaged in succession the various countries of Europe. It may be assumed without exaggeration, that Europe lost during the "Black Death" 25,000,000, or one quarter of its population.*

REVIVAL OF SANITARY SCIENCE.

The great fire of London in 1666, in itself a calamity of the first magnitude, did great good, indirectly, in many ways.

After the fire, some attention was given to the construction of drains for removing the surplus waters of the city, which had hitherto been allowed to flow over the surface. These drains were of very rude construction, and when covered, were invariably of such a size that men could enter them and remove the deposits that were constantly collecting.

After the general introduction of water-closets, about the commencement of the present century, fæcal matter was admitted into the public drains. "Up to about the year 1815, it was penal to discharge sewage or other offensive matters into the sewers; cesspools were regarded as the proper receptacles for house drainage, and sewers as the legitimate channels for carry-

* Hecker, Black Death in the 14th Century.

ing off the surface waters only. Afterwards it became permissive, and in the year 1847 the first act was obtained making it compulsory to drain houses into sewers."*

The construction of systems of impervious, self-cleansing sewers is to be dated from this time. Those previously built had not been of this character; they were merely underground channels of masonry or brick-work, through which water was expected to flow, built without much regard to the laws of hydraulics, and with little or no effort to make them water-tight.

RESULTS ACHIEVED BY MODERN SANITATION.

The effect of the construction of modern systems of sewerage in improving public health, as shown by the reduction of the rate of mortality, has been very remarkable.

The following extract from an address of Capt. Douglas Galton at the Fifth Congress of the Sanitary Institute of Great Britain contains some important facts: —

"It may be accepted as certain that in every case where the sewerage of towns has been devised on sound principles, and where the works have been carried on under intelligent supervision, a largely reduced death-rate has invariably followed. The records of Newcastle afford evidence of this fact. The quinquennial period beginning in 1868 showed a death-rate of 27.6; the quinquennial period ending in 1881 showed a death-rate of 23; whilst the death-rate of 1881 was only 21.7."

"At the recent Sanitary Congress at Vienna, some remarkable results of the effects of the sewerage of certain German towns were given, which are very striking."

"Munich is the residence of one of the ablest sanitarians of Europe, Dr. Pettenkofer. His admirable illustrations of the effect of the impurities which were accumulated in porous cesspits upon the air of the town, and the death-rate of the population, form a text-book of sanitary knowledge."

"At Munich, the enteric fever mortality *per 1,000,000 of inhabitants* for quinquennial periods was as under: —

* Bazalgette, Proc. Inst. C. E., Vol. 24, p. 282.

1854 to 1859, when there were absolutely no regulations for keeping the soil clean . . .	24.2
1860 to 1865, when reforms were begun by cementing the sides and bottoms of porous cesspits .	16.8
1866 to 1873, when there was partial sewerage .	13.3
1876 to 1880, when the sewerage was complete .	8.7

"Similarly at Frankfort-on-the-Main, the deaths from enteric fever *per 10,000* were: —

1854 to 1859, when there was no sewerage . .	8.7
1875 to 1880, when the sewerage was complete .	2.4

"At Dantzic, the figures present some more striking characteristics; the deaths from enteric fever *per 100,000 living* were as follows: —

1865 to 1869, when there was no sewerage and no proper water supply	108
1871 to 1875, after the introduction of water supply.	90
1876 to 1880, after the introduction of sewerage .	18

"Hamburg has been drained by Mr. Lindley, and he has stated that in his plans he carefully followed the principles laid down by Mr. Chadwick. In that town, the deaths from enteric fever *per 1,000 of total deaths* were: —

From 1838 to 1844, before the commencement of the construction of any sewerage works . .	48.5
From 1871 to 1880, after the completion of the sewerage works	13.3

"During the time that the works were in progress, viz., from 1872 to 1874, the mortality from enteric fever *per 10,000 living* was: —

In the unsewered districts	40.0
In the districts for the most part sewered . .	32.0
And in the fully sewered districts	26.8

"These results illustrate the effect of purifying the air of towns by the rapid abstraction of refuse matter, so as to prevent it from remaining and putrefying in and upon the ground."

Mr. Edwin Chadwick, C. B., one of the ablest and most experienced English sanitarians, writes concerning the benefit derived in England from sanitary measures as follows: — *

"Our kinsfolk in the United States have carried with them the erroneous practices prevalent here at home before sanitary science was known, and object to the cost of removing them. It is well that they should be made aware of the greater cost of retaining them."

To show the money gain, as well as the gain in health and life, achieved in England by sanitary measures, as yet incomplete and rudimentary, he adds: —

"Since the International Medical Congress was held, the report of the Local Government Board has appeared, and contains a statement of the progress of sanitary work in England and Wales . . . as follows: —

'Before concluding the part of our report which relates to sanitary administration, it may be useful to draw attention to the annual death-rate for some years past as indicating the effect which recent sanitary measures would appear to have had upon the public health.'

'The following table shows the death-rate for each of the four last decennial periods: —

England and Wales.	Annual death-rate per 1,000.			
	1841-1850.	1851-1860.	1861-1870.	1871-1880.
All causes	22.4	22.2	22.5	21.5
Seven zymotic diseases . . .	. . . .	4.11	4.14	3.36
Fever	. . . .	0.91	0.88	0.49

'From the above figures, it will be seen that, speaking generally, the death-rate of the country remained stationary from 1840 to 1870, but that in the period 1871–80 it fell from 22.5 (of the previous decade) to 21.5; a reduction equivalent to

* Sanitary Engineer, Vol. 4, 1881.

nearly 4½ per cent. It may, therefore, be roughly estimated that about 250,000 persons were saved from death in the ten years 1871–80, who would have died if the death-rate had been the same as in the previous thirty years. If twelve cases of serious but non-fatal illness be reckoned for every death, it follows that about 3,000,000 persons, or over one ninth of the whole population, have been saved from a sick-bed by some influences at work in the past decade which had not been in operation previously. . . .

'Comparing then 1861–70 with 1871–80, it will be seen from the foregoing figures, that, of the entire reduction of 1.0 in the death-rate, more than three quarters (4.14 — 3.36=0.78) come under the head of "the seven zymotic diseases"; of the diseases, that is, which are most influenced by sanitary improvements, and most amenable to control by the action of sanitary authorities. And of this three quarters, just half (0.88 — 0.49=0.39), or three eighths of the entire reduction, is in "fever"; the disease which, more than any other, shows itself in connection with such faults of drainage, of water supply, and of filth accumulation as it is within the province of good sanitary administration to remove.'

"During the decade from 1861 to 1870, there appeared to be no gain from the outlay on sanitary works or on sanitary service in England and Wales; but since then the service appears to have made an effective start, and the pecuniary gain may be thus stated: Under the inquiry as to interments, the cost of funerals — all round — was ascertained to be £5 ($25.00) each. The gain under that head will, therefore, be about £1,000,000 ($5,000,000), by the 250,000 funerals saved during the last decade. The direct cost of sickness has been estimated at about £1 ($5.00) per case. The gain under that head during the decade will, therefore, amount to about £3,000,000 ($15,000,000); a gain, that is to say, by a reduction of medical treatment and other expenses. But the gain to the wage classes from the saving of lost labor will have been far greater. . . .

"A reduction of the death-rate by four and one half per cent is only an instalment of sanitary progress. Thus, in the instance of Croydon, visited by the delegates of the Congress,

the death-rate has been reduced from twenty-five to sixteen per one thousand, chiefly by the methods introduced by the first General Board of Health. . . . On the demonstrations of various model instances, it may be held that the reduction of the general death-rate by four and one half per cent, as reported, satisfactory as this is, cannot be considered more than one third of the results obtainable by advanced sanitary administration and further sanitary works. The pain and misery and the social disorder occasioned by excessive sickness and premature mortality are generally beyond pecuniary estimation."

Among the causes which have operated in England to produce these remarkable results may be mentioned the construction of more perfect systems of sewerage and house-drainage, the gradual disuse of cesspools and wells, the introduction of more copious water supplies, the more efficient scavenging of towns, and sanitary inspection of dwellings, and the purification and utilization of sewage.

SEWERAGE SYSTEMS.

GENERAL PRINCIPLES.

The cardinal principles upon which the sanitation of towns should be based may be briefly stated as follows: —

1. The water supply should be both pure and abundant.

2. All excretal filth, domestic refuse, and dangerous waste products of manufactures should be completely removed beyond the limits of inhabited districts, and be properly disposed of, before any deleterious putrefactive change shall have taken place in them.

3. The process adopted for the removal of objectionable matters should be such that the apparatus, channels, or rivers by which they are conveyed shall not become foul nor communicate any gaseous products of decomposition to inhabited places. No system of sewerage is complete until all nuisances from sewage shall have been prevented.

4. The scavenging of the town should be complete and thorough.

5. The storm water should be conveyed without damage or inconvenience.

6. The level of the underground water should be permanently lowered, by means of thorough subsoil drainage, to a suitable depth below all habitations.

7. A code of effective sanitary laws should be enacted and enforced, and an efficient sanitary inspection should be constantly maintained.

WHAT IS SEWAGE?

The word *sewage* is commonly understood as meaning the foul fluids that are conveyed by sewers, and which vary in their offensive character, from the fetid overflowings of privies to the diluted liquids found in the sewers of large cities. Its meaning, however, is extended in sanitary discussions to include the more solid forms of excrement and filth, without regard to the degree of their dilution or the possibility of their removal by flow. It does not, however, include those solid refuse matters which may be used for animal food, as kitchen garbage, nor those which, like ashes, have no tendency to decomposition.

The sewage usually found in city sewers is of a very complex character. "A large proportion of its most offensive matters is of course human excrement, discharged from water-closets and privies, and also urine; . . . but, mixed with this, there is the water from kitchens, containing vegetable, animal, and other refuse, and that from wash-houses, containing soap and the animal matters from soiled linen. There is also the drainage from stables and cow-houses, and that from slaughter-houses, containing animal and vegetable offal. In cases where privies and cesspools are used instead of water-closets, or these are not connected with the sewers, there is still a large proportion of human refuse in the form of chamber-slops and urine. In fact sewage cannot be looked upon as composed solely of human excrement diluted with water, but as water polluted with a

vast variety of matters, some held in suspension, some in solution."*

The liquid wastes from manufactories, which are frequently permitted to flow into the sewers, sometimes produce a remarkable effect upon the appearance of the sewage; for example, the color of the sewage of Coventry, England, depends materially upon the amount of waste dyestuff present. It is frequently very highly colored.

The methods in use for the removal of sewage may be divided into three general classes: —

1. Sewage interception systems; or dry-sewage processes.
2. The pneumatic systems.
3. The water-carriage system.

SYSTEMS OF SEWAGE INTERCEPTION.

The term *interception*, in connection with the subject of the dry removal of sewage, means the exclusion from the sewers of fæcal matters; the sewers being used only for the removal of surface water and slops, with or without the admixture of urine.

All interception systems partake of the nature of scavenging, inasmuch as they contemplate the accumulation of the sewage and its periodic removal by horses and carts. They differ in the methods and apparatus employed.

SOIL POLLUTION.

The old-fashioned privy vault and cesspool cannot be too strongly condemned. Constructed for the avowed purpose of retaining the solid matters as long as possible upon the premises, they become centres of pollution and infection. The liquid portions, escaping, pollute the soil and neighboring wells; the noxious exhalations arising from their putrefying contents contaminate the air.

The extent to which the contents of a leaking cesspool or privy may pollute the soil is well illustrated by the following: —

"At Charlbury, in consequence of the escape of the contents of a barrel of petroleum or benzoline, which had been buried

* First Report Rivers Pollution Com. (1868), Vol. 1, p. 13.

in an orchard, a circuit of wells sixty feet below and seven hundred and fifty or nine hundred feet distant, became so affected that the occupiers of fifteen houses, containing eighty-two inhabitants, were for ten days unable to use the water for drinking or cooking. The cattle of one of the proprietors, moreover, refused to drink at the spring where they were accustomed to drink. Had this soakage been sewage instead of petroleum, who can doubt that the result might have been wholesale water poisoning and an outbreak of typhoid fever?"*

The more important modern methods of interception are:—

1. The improved form of privy vault.
2. The pail or tub system.
3. The earth-closet system.

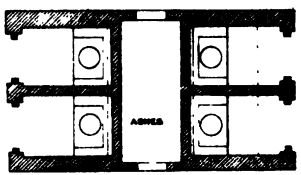
THE MODERN PRIVY.

The improved form of privy was reached by several successive modifications. It was first made impervious by constructing it of more suitable materials; an overflow connected with the sewer being provided to carry off the surplus liquids. Then it was arranged so that some cheap deodorizing substance, such as coal-ashes, could be scattered upon the excreta. A more important step was the contraction of the size of the vault to a small space beneath the seat, thereby necessitating more frequent removals of its contents. In some cases, a trough was placed under the front part of the seat to separate the urine from the solids.

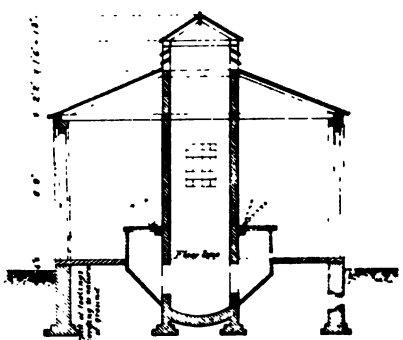
Several forms of improved privies are shown in plate 1.† Fig. 1 represents a privy used at Stamford, England. The bottom of the vault is of brick-work, carefully cemented on the inside, and is concave. The seat can be raised so that ashes may be thrown upon the excreta, and a ventilating shaft is provided. The riser of the seat is of stone and the floors are of non-porous materials. Fig. 2 represents a form of privy used at Manchester before the introduction of the pail system. This privy has a receptacle of limited capacity, and requires empty-

* Child, G. W., Report, etc., *see* Lancet, 1874, Vol. 1, 841.
† Redgrave, Proc. Inst. C. E., Vol. 45, 130.

FIG. 1



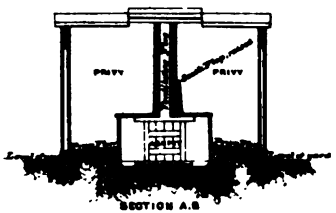
PLAN



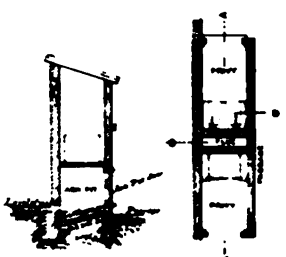
SECTION

MIDDEN CLOSET USED AT STAMFORD

FIG. 2



SECTION A.B

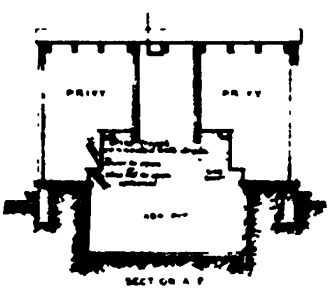


SECTION C.D PLAN

MIDDEN CLOSET USED AT MANCHESTER

FIG. 3

PLAN



SECTION A.B

MIDDEN CLOSET USED AT STOCKPORT

PLATE I

ing every fortnight. The bottom is of glazed earthenware. Fig. 3 shows a privy provided with a trough for the separate conveyance of the urine. It is used at Stockport and in some parts of Leeds.

THE PAIL SYSTEM.

This system consists in the use of small movable receptacles beneath the privy seat, instead of the permanent receiver of the improved privy vault. In its simplest form it consists of a wooden box into which the excreta fall, and which, when full, is emptied into a cart and replaced under the seat. The more usual method, however, is to place a fresh box under the seat, the full one being taken away to be emptied and cleansed.

The difficulty of thoroughly cleansing rectangular boxes led to the substitution of round or oval tubs and pails.

A further modification, the Goux system, consists in lining the bottom and sides of the tub with a layer of loose absorbent materials, kept in place by a movable core or plug, which is removed just as the pail is to be placed under the seat. "All kinds of vegetable and animal fibrous matters, useless for other purposes, are used as absorbents. They are to be mixed in such proportions as may be most convenient, together with a small percentage of sulphate of lime."

Dry rubbish and ashes must be put into some other receptacle. Chamber slops may be emptied into the privy tub. When the fluids exceed the absorbent capacity of the lining, the advantages of the process are impaired or lost. The tubs should, therefore, be emptied quite often.

"There would appear to be but little gain by the use of the Goux lining, as regards freedom from nuisance, and, though it removes the risk of splashing, and does away with much of the unsightliness of the contents, the absorbent, inasmuch as it adds extra weight, which has to be carried to and from the houses, is rather a disadvantage than otherwise, from the manurial point of view." *

The pail system is extensively used at Rochdale, Birmingham, Manchester, and other places in England.

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* Redgrave, Proc. Inst. C. E., Vol. 45, 135 and 136.

At Rochdale,* the tubs are made of paraffine casks, cut in two and supplied with handles (Plate 2, Fig. 1). A strong cast-iron rim is fixed on the inside of the tub, about three inches down, to receive the inner lid,

At Birmingham, galvanized tubs (Plate 2, Fig. 3) are in general use.

The privies at Rochdale (Plate 3, Fig. 1) are all numbered consecutively in a district register. By a good system of accounts, the work of the scavengers is checked, and any omission is at once detected. The whole work is done in the daytime, and every closet is emptied weekly. When a tub is removed, it is covered with its lids, and a fresh tub is left in its place. The privies are provided with a door opening into the passage in the rear of the house, by which access is had to the space beneath the seat. The full tub is placed in a wagon (Plate 4) holding twenty-four tubs, and provided with doors with air-tight rubber joints. In 1874, five such wagons, in full work, collected weekly from 3,354 *privies* in all parts of the town. In 1875, the number of *pails* used was 4,741; in 1876, 5,566.†

At Rochdale, a separate cart accompanies the tub wagon, to collect the ashes and house refuse, which are placed in a special tub. Three such carts, in full work, collected weekly, in 1874, from 3,354 ash places throughout the town.§

The excreta are carried by the carts to some general place of deposit, where they are subjected to the final process of treatment. This varies somewhat at different places.

At Birmingham, where the process has been carried to the greatest perfection, the pails are emptied into a vat as soon as they reach the place. A certain amount of sulphuric acid is here added to fix the ammonia. The vat is then emptied, the contents passing into a drying machine, which consists of a steam jacketed cylinder, within which are revolving arms, which keep the contents continually agitated. The material, when dried, is in the form of a coarse, moist powder, and is bagged for sale.

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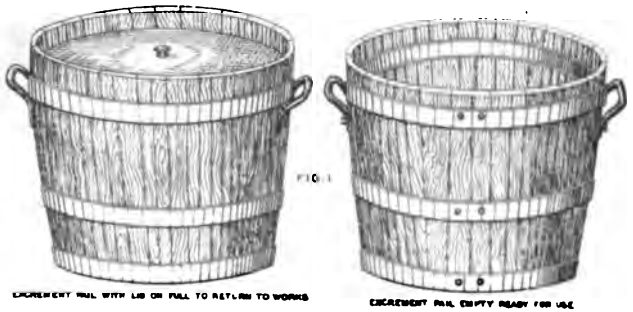
* Redgrave, Proc. Inst. C. E., Vol. 45, 135 and 136.

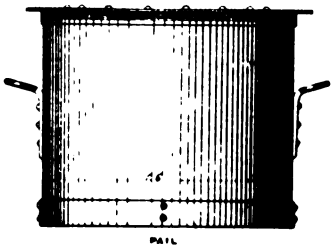
† Taylor, Proc. Inst. C. E., Vol. 45, 177.

§ Redgrave, Proc. Inst. C. E., Vol. 45, 137.



EXCREMENT PAIL WITH LID OR PAIL TO RETURN TO WORKS

EXCREMENT PAIL EMPTY READY FOR USE



PAIL

FIG. 3

MOULD

FIG. 4

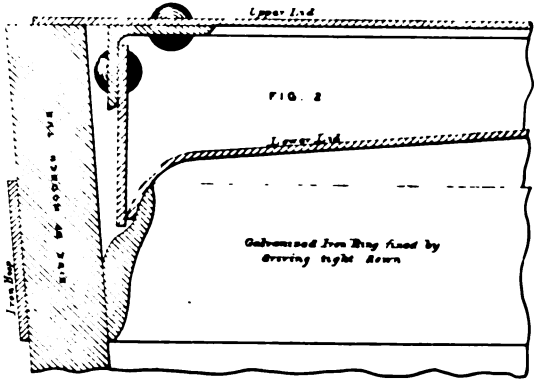
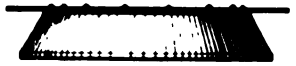


FIG. 2

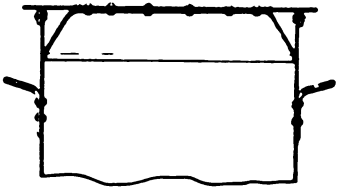
PART SECTION OF TUB

ROOKDALE PAIL AND COVER

Full Size



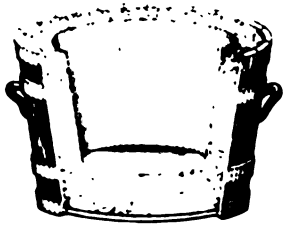
LID



SECTION SHEWING THE LID IN POSITION

GALVANISED PAIL AND COVER

Scale ½ Inch = 1 Foot



ABSORBENT RECEPTACLE

USED PAIL USED FOR "EARTH" SYSTEM

TUBS USED IN THE PAIL OR TUB SYSTEM

PLATE II

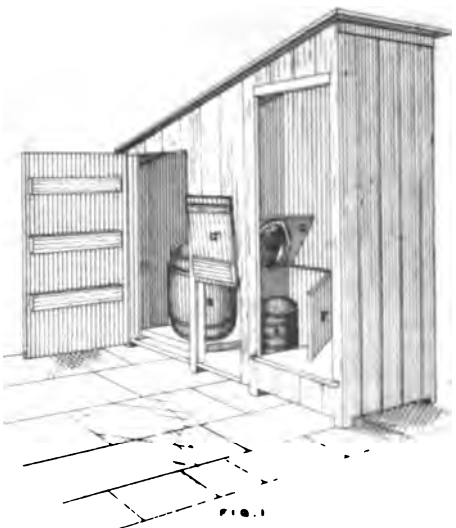


FIG. 1

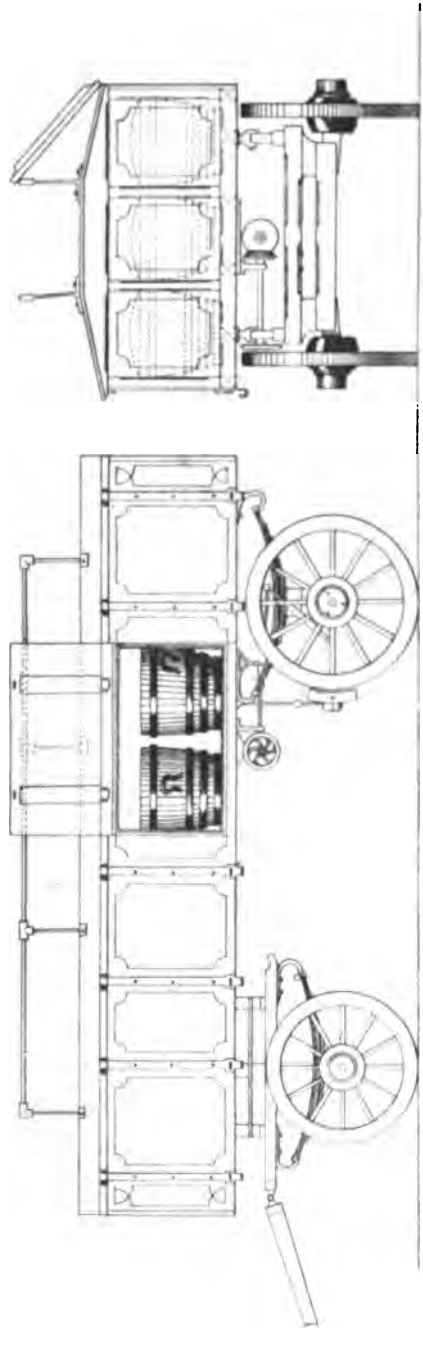
ROCHDALE CORPORATION PATTERN PAIL CLOSET
A. Excrement pail. B. Ash tub. C. Seat cover (raised). D. Iron collar below seat reaching slightly into pail when cover is down. E. Hinged upright of seat. G. Door admitting from outside to excrement pail.

FIG. 2

MANCHESTER CORPORATION DRY ASH CLOSET
aa. Screens to separate cinders from ashes and to direct the latter into the excrement pail.

PLATE III

PLATE IV



The heat required is obtained almost entirely by burning the cinders and garbage collected in the town, which are brought to the same establishment for disposal. The rubbish is examined, and anything of value is picked out, such as rags, bones, old iron, tins, bottles, etc. These are piled separately and sold. The "clinker," resulting from the combustion of the cinders and garbage, is ground to powder, and used as an ingredient for making cement mortar, and for other purposes.

The number of pails in use at Birmingham at the present time is about 40,000, representing a population of 250,000. Their contents are collected weekly. The number of pails is said to be increasing.

At Manchester, the works are of a cruder sort, but the process is essentially the same.

The pail system, at its best, is an offensive method for the collection and disposal of excreta, and its nature is such that it would not be tolerated in any community in this country.

THE EARTH-CLOSET SYSTEM.

Under this head are considered the various systems by which pulverulent deodorizers are applied to the excreta during their storage upon the premises. These systems may or may not include a movable receptacle or pail.

The most important types are: —

1. The earth-closet proper.
2. The ash-closet.
3. The charcoal-closet.

The dry-earth system for the removal of sewage was designed and perfected by the Rev. Henry Moule, M. A., vicar of Fordington, Dorset. It is thus described by Dr. Buchanan: —*

"It consists in the application, with the greatest procurable detail, of dry earth to fresh human excrement, and in the subsequent removal and use of the mixture for agricultural purposes. In so far as detailed application is not made, or as the earth is not dry, or the excrement not fresh, or the mix-

* Twelfth Report Medical Officer of the Privy Council, 1869.

ture otherwise dealt with, the dry-earth system is departed from. . . .

"As regards the principle of the earth-closet, the evidence as to the powers of dry earth is unequivocal. If about a pound and a half of suitable earth, carefully dried, be thrown over a dejection, all smell from it is forthwith removed; and if the same quantity be mixed with half a pint of urine, the latter is absorbed. The mixture of earth with stool and urine is not only inoffensive when fresh, but remains so after keeping for two or three months, or longer."

"The process which goes on in the mixture is obviously one of disintegration and of some combination between the earth and the organic matter, as is evidenced by the disappearance of stools and even of paper among the other constituents of the compost. But the absence of fœtor from the mixture of earth with stool or urine, even with prolonged keeping, shows that decomposition in the ordinary sense does not take place. . . .

"In order that the described result shall be efficiently brought about, the quantity and quality of the earth have to be considered. With any quantity materially less than a pound and a half to the average dejection (unless some artificial means not generally applicable of mixing are had recourse to), a tendency to wetness remains, and more or less fœtor results. If much more earth is used, the proportionate agricultural value of the product is lessened. The quality of earth as affecting its power of producing an inoffensive compost with excrement is of at least equal importance with its quantity. Sand and gravel have almost no power in this respect. Chalk has very little. Clay stands very high in rank. Properly dried, it falls readily into a convenient powder, which has great power of absorption, and of preventing offensive change. High in rank also is surface earth, that which is loamy being preferable to any of peaty character. One of the best of all earths is the brick earth of the drift. Earths which already contain some quantity of organic matter are very suitable. . . .

"The mixture of excrement with earth, after being kept awhile and then dried, has again the power which the original earth possessed of absorbing and making inoffensive any stools

and urine to which it is applied. This power is so marked that it has repeatedly been alleged to me that the earth (especially if clay) acts better a second time than the first; and I can answer from my own observation that earth used three or four times over, with drying at the proper stages, will render excrement quite inoffensive. . . .

"This power of using earth several times over . . . has an important economical bearing upon the applicability of the system. . . . The limits of this power do not appear to have been reached, but, for experiment's sake, the earth has been employed a dozen and more times over, when it must have come to have more than half its bulk of excrement, with the same result on the dejections as at first, but with the other result of getting a manure too strong for use by ordinary methods to the land."

Opinions differ concerning the value of earth-closet compost as manure. Dr. Buchanan* estimates its value at £3 per ton, for "earth that has been *three* times through the closets." He also cites the opinions of two farmers who estimated by actual trial that the earth which had passed *once* through the closets had "a minimum agricultural value of £3 per ton." On the other hand, Mr. Radcliffe, writing in 1874, after stating that the opinion held at the time (1869) when Dr. Buchanan made his inquiry still prevailed, added:—†

"Drs. Gilbert and Voelcker, studying the question chemically, have shown that the earth-closet manure after it has been charged twice, or even thrice, is no richer than good garden mould."

The form of an earth-closet is immaterial. It consists of a seat with a receptacle beneath for the excrement, which is preferably impervious and movable, but may be fixed. The closet may be out of doors, or may be a portable cabinet in the bedroom.

THE ASH-CLOSET.

This closet is similar to the earth-closet in its object, the difference being that sifted coal ashes are used, instead of dry

* Buchanan, *loc. cit.*

† Radcliffe, 2d Report of Medical Officer of Privy Council, 1874.

earth, to deodorize the excreta. Its action is not as efficient as earth, nor is the resulting compost as valuable. The defects arising from the imperfect action of coal ashes as a deodorizer have been urged, unjustly, against the earth-closet, of which the ash-closet is but an imperfect imitation.

THE CHARCOAL-CLOSET.

The valuable deodorizing properties of charcoal have led to its application to the dry removal of sewage in a manner similar to the earth-closet method. Charcoal made from street sweepings and from seaweed have both been employed for the purpose. With the latter kind of charcoal, the development of the method into a system has been attempted.

The system contemplates the charring of the mixture of excrement and seaweed charcoal, thus making a new grade of charcoal, which may be afterwards used to deodorize excrement. Certain valuable chemical products are also obtained during the charring process. The charcoal may also be converted into a valuable manure. The weight is increased, at each reburning, and all the potash and phosphates of the excrement are retained.

The quantity of charcoal needed to thoroughly deodorize excrement is about one fourth, by weight, of the dry earth necessary for the same purpose. In case the urine is kept separate from the solids, from one half ounce to three fourths ounce is sufficient for each use of the closet. Thus an important advantage is gained over the dry-earth system, by reducing the weight of the material to be removed. Chamber slops and sink water should be excluded from charcoal-closets.

Charcoal-closets have been used in Glasgow and vicinity with a certain degree of success.

CONCLUSIONS AS TO SEWAGE INTERCEPTION.

From a sanitary point of view, all sewage-interception systems are imperfect, since they require the excreta to be stored about the premises for a certain period, longer or shorter according to the system employed. As sewage begins to putrefy in two or three days, to obtain the best sanitary results it is

essential that it be speedily and completely removed. This condition cannot be complied with by any system of sewage interception without great inconvenience to the household.

Nevertheless, there are households and communities whose sanitary conveniences are so imperfect that the introduction of a good system of sewage interception would be considered a great blessing. Such may be found in country residences, and villages where an efficient water supply and system of sewerage are impracticable on account of cost or other considerations.

Sewage-interception systems are imperfect from an engineering and economic point of view, because they fail to provide for the removal of chamber slops and sink water, and dispose of the urine to a limited extent only. Neither do they provide for the drainage of the soil nor for the removal of surface water. Thus it is seen that the establishment of a perfect system of sewage interception does not relieve the community from the necessity of constructing a complete system of sewerage for the removal of these liquid wastes. The cost of such a sewerage system would not be affected by the exclusion of the fæcal matters, their volume being relatively small.

It has also been proved by chemical analyses that the exclusion of human fæces from the sewers has a very slight effect upon the composition of the sewage. This conclusion was reached by the second Rivers Pollution Commission, after an examination of the sewage of fifteen towns in which fæces were excluded from the sewers, and of sixteen towns in which water-closets were used.* Thus it is seen that the cost of an interception system would be an additional and unnecessary expense in towns that have reached that stage of development in which sewers for the removal of liquid wastes have become a necessity.

* First Report, Rivers Pollution Commission (1868), Vol. I. (1870), page 30.

THE PNEUMATIC SYSTEMS.

THE LIERNUR SYSTEM.

The object of the pneumatic systems is to remove sewage to some central depot as frequently as may be desired, without the annoyance of scavengers, and without its excessive dilution by the admixture of water, which increases the difficulty and expense of manufacturing a dry manure from it.

The most widely known pneumatic system is that of Capt. Charles T. Liernur, which has been used in Holland, in portions of Amsterdam, Leyden, and Dordrecht, and also to a limited extent in Prague and Hanau.

The Liernur system consists, primarily, of a net-work of cast-iron pipes, jointed like water mains, and completely air-tight, for the removal of fæces, urine, and chamber slops from dwellings, and the entire drainage from hospitals, by pneumatic suction. Secondly, it contemplates the removal by gravity of domestic, kitchen, and laundry slops, the rain-water from roofs, yards, and streets, and the drainage of the soil, by means of an entirely distinct system of pipes or sewers. This second system, although an integral part of the general scheme, has never been constructed in the places using the Liernur method.

The pneumatic pipes are usually of the same diameter, five inches, throughout the entire system. Those from the closets in the houses connect with the pipe in the street, which leads to a small, air-tight, cast-iron reservoir (Plate 5, Fig. 2, and Plate 6) placed at the intersection of the streets. This reservoir receives the sewage from a certain district of houses. The several street pipes connected with it are each furnished with a stopcock to control the vacuum.

At some convenient place a general collecting station is established, provided with large air-tight reservoirs. Here a steam-engine operating an air-pump produces a partial vacuum in the large reservoirs and in main pipes connected with them, laid in the principal streets. The main pipes are joined to the

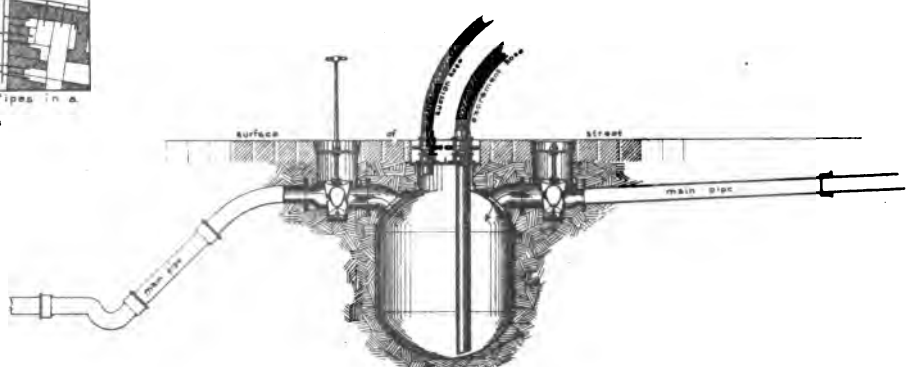
General Plan of a Pneumatic System of Pipes in a City District.

● Reservoirs ——— Pipes

FIG. 1

Details Of Parts Of
Liernur's Sewerage System

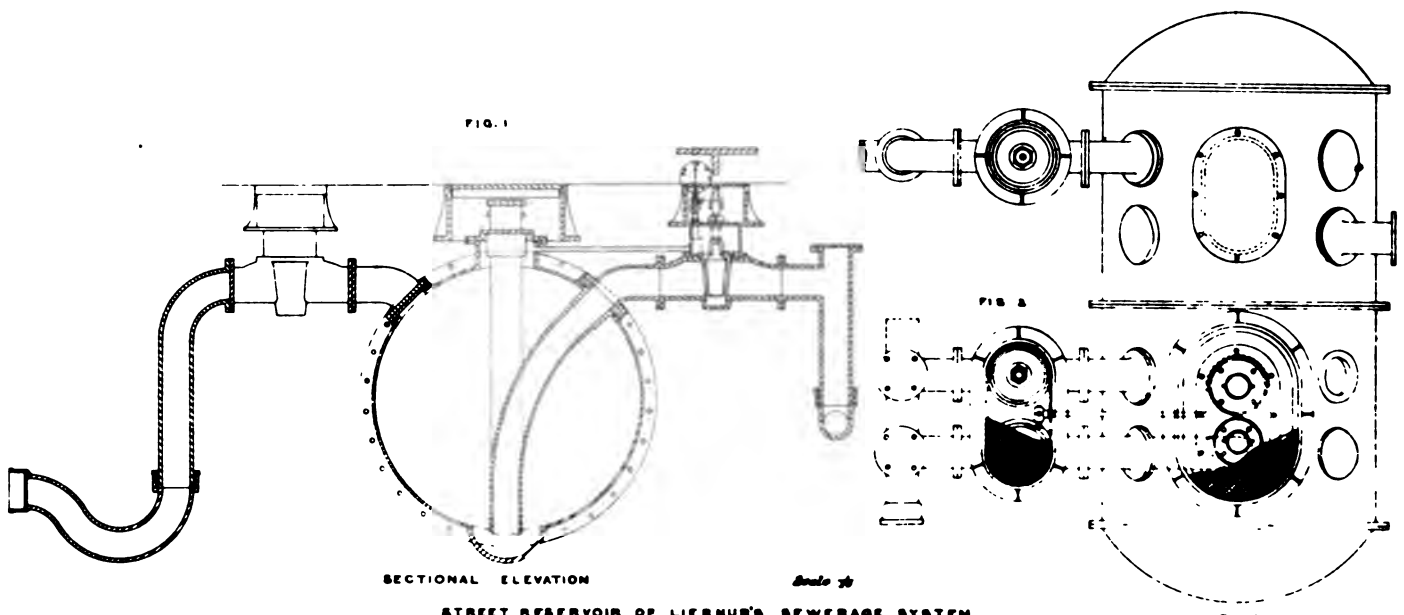
Scale 1/6



STREET RESERVOIR

FIG. 2

PLATE V



STREET RESERVOIR OF LIERNUR'S SEWERAGE SYSTEM
IN USE AT AMSTERDAM HOL.

PLATE VI

street reservoirs by two connections, each having its stopcock. One of these, merely passing through the top of the street reservoir, serves to exhaust the air; the other, passing into its interior and nearly to its bottom, is used to extract the sewage.

The operation then is as follows:* "The air-pump in the central building maintains during the day a vacuum in the reservoirs underneath, and in the whole length of the central pipes connected therewith. Patrols of two men each parade the district. Coming to a street tank, they open the lids by which access is given to the cocks which shut off each pipe from the tank; one man fixes his key upon the cock connecting the central or vacuum pipe with the tank, and the other has his upon the cock belonging to one of the street main pipes leading to the houses. The moment the first man turns his key he opens the connection between the central station and the tank, the air contained in which is at once exhausted and a vacuum established, the extent of which is indicated by a small vacuum meter. He then shuts the cock, while the other man, by turning his key, lets loose the force upon one of the pipes leading by its branches to the houses. This action repeated once or twice brings the fæcal matter into the tank.

"In the same way, a second, third, and fourth pipe, each leading to different streets, may be dealt with, and the whole fæcal products of the little drainage district belonging to the tank be thus collected in it. Before leaving the tank, the matter must be despatched to the central station; and this is done by simply opening the second connection of the vacuum pipe, which dips into the well of the tank, when all the matter is at once sucked up and despatched towards the central station."

During the construction of the pneumatic system, and before the establishment of the central station, the street reservoirs may be operated by a portable steam air-pump and an air-tight tender, in which latter the excreta may be removed.

Works are being constructed at the central station in Amsterdam by which the sewage will be evaporated to dryness by

* Adam Scott, Jour., Soc. of Arts., Vol. 23, p. 457.

means of superheated steam and special machinery, the product being a dry manure or *poudrette*.

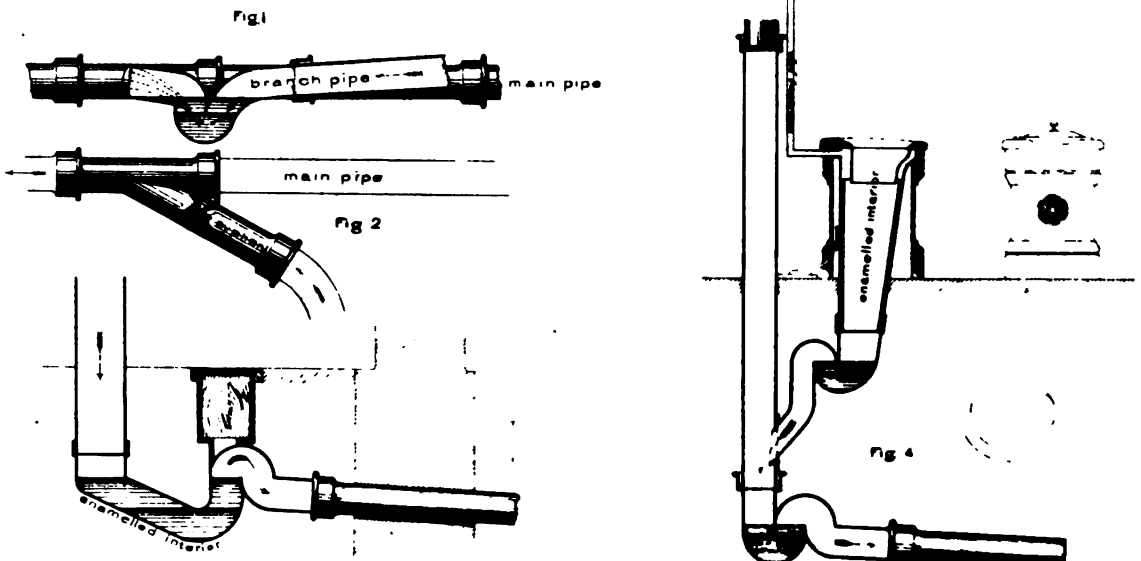
At present, the fæcal matters are barrelled for use as liquid manure and removed by boats.

An interesting and important feature of the Liernur system is the method adopted to preserve the vacuum in the pipes and to secure the removal of the sewage. It is impracticable to move liquids wholly by means of air pressure through horizontal pipes, or those inclined downwards. Air pressure, on the contrary, will raise liquids without difficulty through vertical pipes, or those inclined upwards. The pneumatic pipes of the Liernur system are consequently laid in a series of undulating grades, having rises, up which the sewage is raised by suction, followed by declivities, down which it flows by gravity.

All the branch pipes leading from the houses to any given street main are so arranged as to have a uniform suction lift, or step, so that the sewage has to be raised an equal amount in every instance. Consequently they are all *emptied simultaneously* at the instant when the suction is strong enough to overcome this resistance, which is uniform throughout the district. The sewage, however, *commences* to flow from the houses at different instants according to the quantity which has accumulated.

Two varieties of closets may be used in connection with the Liernur system. Persons accustomed to the water-closet, or desiring one that shall be cleansed with water, are supplied with a closet which, by certain mechanism, is flushed by a limited amount of water every time it is used. The quantity is limited to prevent the dilution of the fæcal matters.

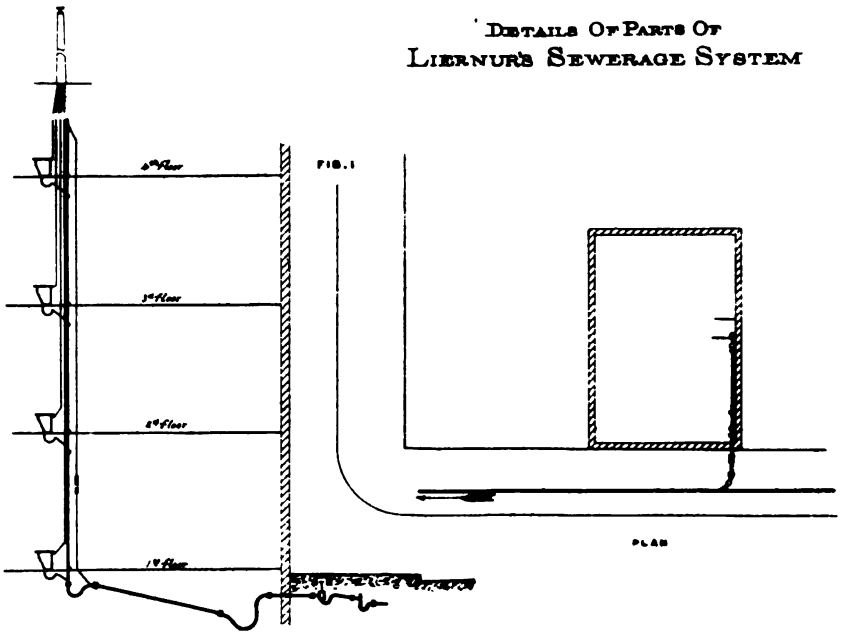
The closets for the use of the lower classes are, however, of a different character. They have no movable mechanism, and are used without any water whatever. The pneumatic privy (Plate 7, Fig. 4) consists of a hopper with a concentric flange at its top, the annular space between them being ventilated by a small pipe running to the top of the house and furnished with a ventilator at its upper end. The hopper is so shaped that the fæces fall directly into a trap beneath without touching its sides. The trap always remains full of fæcal matter, and overflows by



DIAGRAMS SHOWING ARRANGEMENT OF
LIERNUR'S SEWERAGE SYSTEM
In Private Houses

PLATE VII

Details Of Parts Of
Liernur's Sewerage System



VERTICAL SECTION

FIG. 1

PLAN

GENERAL ARRANGEMENT OF HOUSE-DRAINS

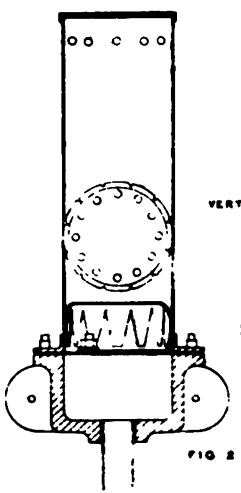
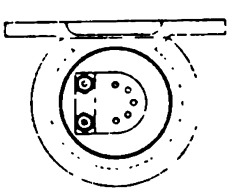


FIG. 2

VERTICAL SECTION



PLAN OF BOTTOM

VENTILATOR AT TOP OF SOIL PIPE WITH RECEPTACLE FOR VEGETABLE MATTER

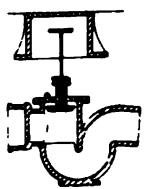
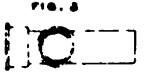


FIG. 3



VERTICAL SECTION AND PLAN OF VALVE

PLATE VIII

gravity into an inclined pipe, which discharges into the soil pipe. The odors arising from this fæcal trap are expected to pass up the small ventilating pipe to the outer air, and not through the opening in the seat into the room; an expectation which, it is said, is often unsatisfied. The throat of the trap is made smaller than the soil pipe, to prevent large foreign substances from getting into and obstructing the pipes. Both forms, the water-closet and pneumatic closet, discharge into the soil pipe which leads to the pneumatic trap or step, in the house drain. It is this latter trap only which is emptied periodically by the vacuum. The soil pipe extends upwards to the open air, its open end supplying the air necessary for the pneumatic action.

Opinions concerning the Liernur system differ greatly, according to the standpoint from which it is viewed.

In Holland, where the lowness and flatness of the country render the subsoil drainage of towns impracticable except at an enormous cost, and where their surface drainage forms a part of the general drainage system of the country, the Liernur system has reached its greatest development. In other localities where these conditions do not exist, the Liernur system would prove excessively expensive, requiring, as it does, a duplicate set of sewers for the removal of kitchen slops, storm and subsoil water, the details and cost of which would not be essentially affected by the exclusion from them of the fæcal matters.

In 1876, an expert committee, appointed by the Local Government Board of England to inquire into the several modes of treating town sewage, reported concerning the Liernur system:* "One of the most complicated and costly processes for dealing with the solid of human excreta (not with town sewage) is the system known by the name of the inventor, Capt. Liernur. The pneumatic system has been partially introduced at Leyden, Amsterdam, and Dordrecht, where we have seen it working. These towns are flat, and are intersected by canals and open water-courses. The towns are not sewered on the English plan,

* Sewage Disposal. Report of a Committee [etc]., 1876. (C.—1410.)

but have surface gutters along the margins of the footwalks, into which surface water flows and the inhabitants throw their waste water and liquid household refuse. . . . If the towns of Holland, or portions of such towns, by reason of peculiarities of site and climate, cannot be sewered on English principles, and if the pneumatic system is as cheap as any of the movable pail systems, it may be the best, under such conditions, for Holland, because, if worked in accordance with the rules laid down, the excreta will be removed daily without the intervention, trouble, and dirt involved in the pail system. . . . We do not know one English town in which the apparatus, if adopted, would be other than a costly toy."

THE BERLIER SYSTEM.

This system is of more recent origin than the Liernur, and has been developed from the necessities of the city of Paris, where it has been introduced for trial on a limited scale.

The sewers of Paris receive the surface and subsoil water, the sink drainage of the houses, and, to a small but increasing extent, the urine, and the overflow from cesspools, etc. The fæces have until very lately been excluded entirely from them; but, by a recent resolution of the Commission on the Sanitary Improvement of Paris, such matters have been allowed to enter certain sewers where the conditions are favorable to their rapid removal.

Ordinarily at Paris, the fæces pass into water-tight cesspools (*fosses permanentes*), not connected with the sewers, from which they are pumped by pneumatic pressure into cylindrical iron carts, which, when full, are tightly closed and driven to the places of deposit. Frequently the fæces pass directly into wooden casks (*fosses mobiles ordinaires*), there being no cesspool. By the modern system of "*appareils diviseurs*" or "*tinettes filtrantes*," the solids are collected in movable receptacles, from which the liquids overflow either to the cesspool or to the sewer. These movable receptacles are in the cellar, and are connected with the soil pipe by a sliding joint. When full, they are removed, and empty ones are left in their place, after

the manner of the pail system, of which this method is a modification.

The inconvenience, nuisance, and danger of infection arising from the emptying of these numerous receptacles and the cartage of so much excrementitious matter through the streets became so great that a change was demanded.

As early as 1861, a pneumatic arrangement was suggested by M. Belgrand, *Inspecteur-Général des Ponts et Chaussées.*

It was afterwards developed into a system by M. Berlier, and was first tried in 1880, at Lyons, where it successfully removes the sewage a distance of four kilometers (2.5 miles).

In 1881, M. Berlier presented to the Municipal Council of Paris a scheme for the interception of the excreta from the sewers, and their removal by pneumatic action through an independent system of pipes to a collecting station in the suburbs, and he was permitted to introduce his system, for trial, in portions of the 8th and 17th Arrondissements, a district extending from the Madelaine to Levallois-Perret, a suburb on the northwest side of the city, at which latter place he established a pumping station near the junction of two main intercepting sewers of the Paris gravitation system.

At this station is a steam-engine, an air-pump, and a reservoir or vat for the reception of the sewage. The steam-engine also drives a rotary pump, which forces the sewage from the vat to an outfall at the river. This disposition of the sewage is merely provisional, the scheme contemplating the pumping of the sewage through pipes to some distant point where it may be utilized. The Berlier system proper ends with the delivery of the sewage into the vat by the pneumatic pipes, the subsequent pumping presenting no unusual features.

The main pneumatic pipe leading from the pumping station is laid within the intercepting sewer from the right bank of the Seine as far as the Place de la Concorde.

Throughout its extent, which is about five kilometers (3 miles), and includes four siphons, its diameter is fifteen centimeters (6 inches).

The pipes leading through the different streets are ten centimeters (4 inches) in diameter. One of these, that in the Rue

de la Pépinière, receives the sewage of the barracks in that street, containing about one thousand men. The pipes leading to the houses are also ten centimeters (4 inches) in diameter.

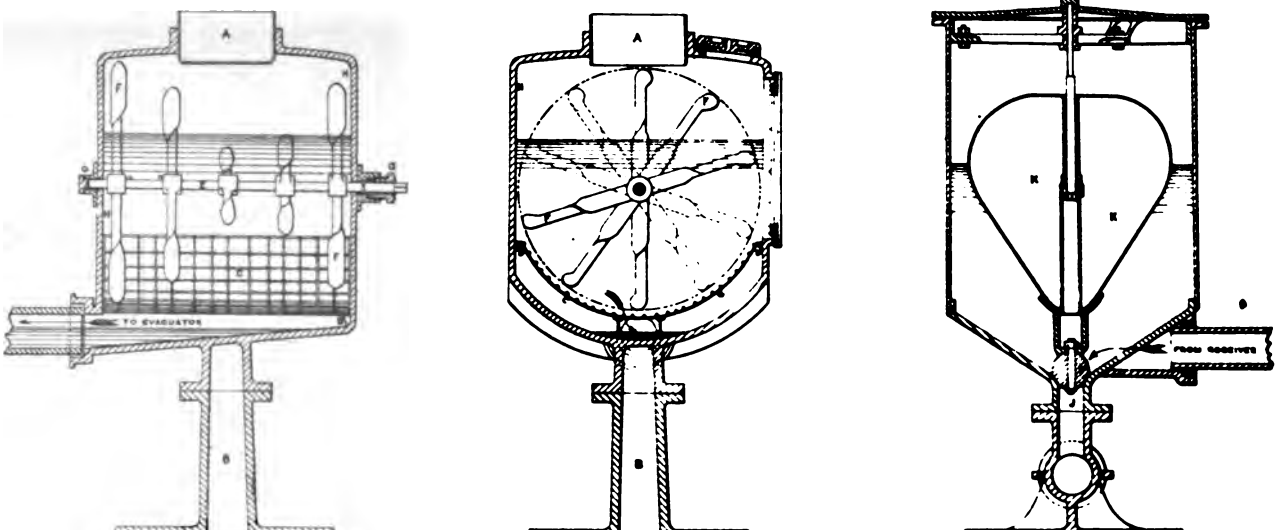
The arrangement within the houses forms a distinctive feature of the Berlier system. The soil pipe is connected with the top of a rectangular iron vessel, or "receiver," placed in the cellar; no modification of existing soil pipes or closets being necessary. The sewage entering the receiver (Plate 9, Figs. 1 and 2)* drops upon a grating of heavy iron wire, with meshes of four centimeters ($1\frac{1}{8}$ inches).

This grating catches and retains any foreign substances which might obstruct the pipes, its meshes being wide enough to permit the passage of ordinary sewage matter. A horizontal axle passes through the receiver, and is furnished with several arms of different lengths. By turning this axle, the presence of any large object is detected, and it is removed by opening the receiver. The rotation of the arms also serves to agitate the contents of the receiver and break up any masses of fæcal matter that may have accumulated. A person specially employed for the purpose visits the houses at intervals, to inspect the receivers and remove any large object they may have retained.

The sewage passes by gravity from the receiver to another receptacle, called the "evacuator." This (Plate 9, Fig. 3)* is a cylindrical iron vessel with a conical bottom, at the apex of which is the pneumatic pipe. Within the cylinder is a large, pear-shaped float, which slides on a vertical rod attached to the top of the cylinder. At the point of the float is an elastic rubber ball, which closes the opening into the pneumatic pipes when the float is in its lowest position; it being held to its seat both by the weight of the float and by the suction of the vacuum which is constantly maintained in the pneumatic pipes. The sewage, gradually filling the evacuator, causes the float to rise when it has reached a certain level, when the contents of the evacuator are immediately sucked into the pneumatic pipes,

*Adolphe Smith, Pneumatic Drainage (etc.).

Part of aparatus of J.B.BERLIER'S SYSTEM of pneumatic drainage



A. House drain pipe B. Stand C. Wirework double bottom or strainer D. Supports for strainer E. Axle F. Buckets G. Water tight bearings H. Iron sides of receiver I. India rubber valve J. Outlet communicating with pneumatic tubes K. Floater.

FIG. 1 SECTIONS OF RECEIVER FIG. 2

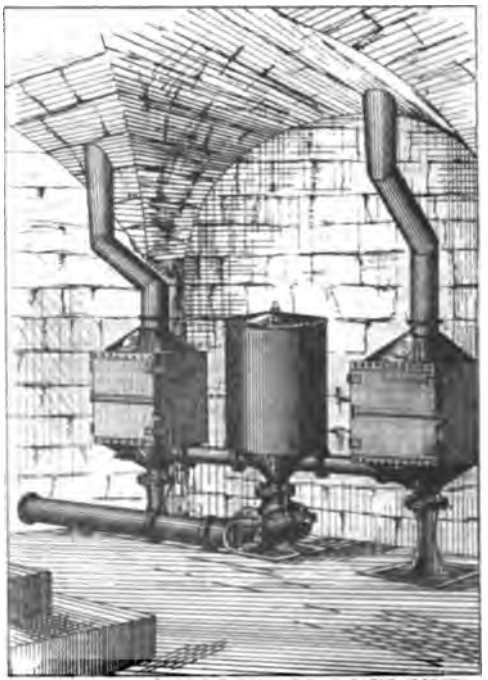
FIG. 3 SECTION OF EVACUATOR

PLATE IX

FIG. 1

PÉPINIÈRE BARRACKS

FIG 2



PRIVATE HOUSE AT Nº 4 RUE DE LA BIENFAISANCE

PARIS

SKETCHES SHOWING ARRANGEMENT OF THE BERLIER SYSTEM IN PUBLIC AND PRIVATE BUILDINGS

PLATE X

the opening to which is closed by the dropping of the float before the entrance of any air. Two or more receivers may be connected with one evacuator if necessary.

The vacuum required to operate this apparatus does not exceed one hundred and fifty millimeters (6 inches) of mercury. Experiments continued for three months at the barracks of the Pépinière show that a vacuum can be easily maintained in an extensive system of pipes. With the pipes under consideration, which are of cast-iron, united by sleeves and lead joints, a vacuum equivalent to seven hundred millimeters (27⅝ inches) of mercury has been obtained in a few minutes.

The action of the sewage within the pipes was observed by placing pipes with glass sides at various points. Throughout the system, the solid matter remains in suspension in the liquid, as if continually stirred. This agitation is produced by the circulation through the sewage of the gases liberated by the reduction of pressure and extracted from it by the air-pump.

M. Berlier designs to finally dispose of the matter gathered at the pumping stations of his system by establishing lines of pipes many miles in length, which, working either under pressure or by vacuum, would convey all the matters to special establishments, at great distances from Paris, where they would be transformed into ammoniacal products. He would also provide branch pipes at various places along these main lines which would distribute the matters to those wishing to use them to enrich the soil. He considers that the revenue derived from these two modes of utilization would certainly exceed the interest on the capital invested and the general expenses.

From this description, it will be seen that the Berlier system differs from the Liernur in the omission of the street reservoirs, in maintaining a constant vacuum throughout its pneumatic pipes, and in removing sewage from the premises whenever a sufficient quantity has collected to operate the evacuator. In the Liernur system, the vacuum in the house drains and the consequent removal of the sewage are intermittent, and depend upon the fidelity of the men who periodically visit the street reservoirs.

The Berlier system contemplates the removal of excreta only,

leaving the house drainage, the surface water, and the subsoil water to be carried off in a distinct system of sewers. It is the outgrowth of certain local conditions, and, like the Liernur system, cannot be economically introduced where other conditions prevail. The system has not as yet passed beyond the experimental stage. That it possesses sanitary advantages over the methods commonly in use in Paris is shown by the fact that the thousand soldiers in the barracks of the Pépinière, where this system is in operation, were the only troops in Paris that escaped a recent typhoid epidemic.*

THE SHONE SYSTEM.

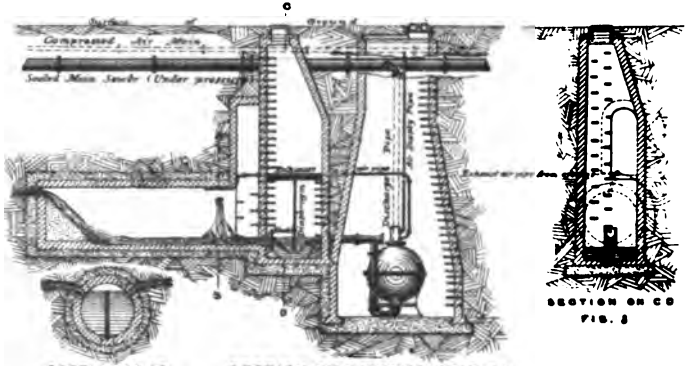
This, although classed among the pneumatic systems, is a combination of what is technically known as the separate system of water carriage, with a method of pumping sewage by the direct action of compressed air, invented by Mr. Isaac Shone, a mining and civil engineer of Wrexham, Wales. It differs from the pneumatic systems already described by using a plenum instead of a vacuum.

In applying this system to a city or town, the house drainage, comprising excreta and all liquid wastes, is conducted by gravity to a low point in each drainage district, through ordinary sewers, in which nothing else is permitted to flow.

At each of these points is situated a "pneumatic ejector," into which the sewage flows, and by which it is raised, by the direct pressure of compressed air, to any required height, into a system of cast-iron pipes, jointed like water pipes, in which the sewage is forced to the point of discharge. This may be at the sea-shore, far below the high or low water level, or may be at a sewage farm, where the sewage can be applied to the land. Another arrangement is to deliver the sewage from the ejectors into an upper tier of gravity sewers leading to the outfall. The choice between these two methods depends upon the topography of the locality.

The air which forms the motive-power of all the ejectors is compressed at some convenient place by a compressor operated

* Pall Mall Gazette, April 2, 1883, Adolphe Smith, *loc. cit.*



SECTION ON AB
FIG. 3

SECTION OF EJECTOR STATION
FIG. 1

SECTION ON CD
FIG. 2

EJECTOR STATION
FIG. 4

DETAILS OF ISAAC SHONES PNEUMATIC SEWERAGE SYSTEM

PLATE XI

by steam or water power. Thence the compressed air is supplied to the ejectors through small iron pipes laid through the streets.

The system is confined to the removal of house sewage both to prevent its dilution, and to render more uniform the volume of liquid to be raised by the ejectors; it being evident that, should storm water and subsoil drainage be admitted, the ejectors would either be unable at times to perform the work required of them, or would need to be so large that they would not work economically under ordinary conditions. Storm water and subsoil drainage are therefore expected to be conveyed in a distinct system of sewers.

The general arrangements of ejector stations are shown in Plate 11.* In Figs. 1, 2, and 3, the sewage is discharged from the gravity sewers into a receiving chamber, from which it passes into a separating chamber, where all floating substances are arrested, and thence into the ejector. In Fig. 4, the sewage passes directly from the gravity sewers into the ejector.

The ejector is made in several forms, one of which is shown in Plate 12, Fig. 1,* which represents the ejector empty. The action of the ejector is more readily seen in Figs. 2 and 3. Fig. 2 shows the ejector while it is filling. At the top of the ejector is an automatic-valve apparatus, controlled by a weighted lever. A rod connected with one end of this lever passes through a stuffing-box, and into the interior of the ejector. On this rod is a reversed cup or "bell," and connected with its lower end is a weight or "cup." While the ejector is filling, the valve marked 2 is held to its seat by the pressure from the rising main, and the valve marked 1 is lifted by the pressure of the inflowing sewage. The air within the ejector passes out through an exhaust port and pipe to the man-hole or sewer.

When the ejector is full, the "bell" is affected by the buoyancy of the water, and the weighted lever falls, closing the exhaust port; and immediately afterwards opening the inlet port, admitting compressed air to the interior of the ejector. This acting upon the surface of the sewage causes the valve 1 (Fig. 3)

* Shone, Pneumatic Sewerage System.

to close and the valve 2 to open and permit the passage of the sewage to the pressure main in the street at a higher level, to which it is raised by the force of the compressed air. When the sewage has fallen to the bottom of the "cup" suspended from the valve mechanism, its buoyancy has been withdrawn, and the "cup" falls, and reverses the valves, closing the inlet port, and immediately afterwards opening the exhaust port, through which the compressed air within the ejector escapes by a pipe leading to the man-hole or to the sewer. The atmospheric pressure being restored within the ejector, the valve 2 closes, and it begins to refill with sewage.

From this description, it will be seen that the Shone system is essentially a method of pumping sewage in detail by means of small pneumatic pumping engines situated in different parts of the city, all of which are operated by power generated at a single station. The system may be applied to the entire sewerage of a city, or may be confined to special districts, according to circumstances.

The Shone system is particularly valuable in the sewerage of towns where fall sufficient to produce a proper velocity of flow cannot be obtained, and where it is impracticable to convey the sewage to one general pumping station, since, in this system, it is not necessary to follow the general topography; but the sewers may be given such grades as may best promote the rapid discharge of the sewage. An ejector may be placed wherever these grades cause the depth of the sewer to be excessive, and the sewage may be raised to a height from which it may flow to the outfall, either under pressure or by gravity. The cost of an equal number of small steam pumps, with their appurtenances, to do the work done by the ejectors, would be very great.

As a basis for comparing the cost of pumping all the sewage of a town at a single pumping station with the cost of pumping the same in detail by a number of Mr. Shone's ejectors, it has been estimated that,

"The efficiency of the compressed-air process, when used with Mr. Shone's ejector at a pressure of twenty-nine pounds per square inch, competent to lift sewage some sixty-seven feet,

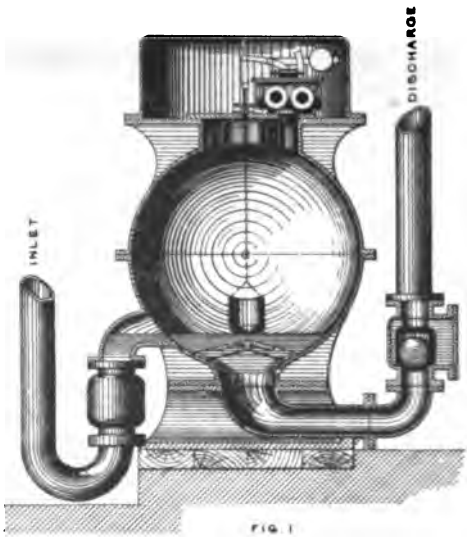


FIG. 1

SHONE'S PNEUMATIC EJECTOR

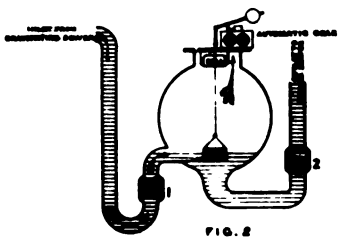


FIG. 2

FILLING

FIG. 4

SECTION

DETAILS OF ISAAC SHONES PNEUMATIC SEWERAGE SYSTEM

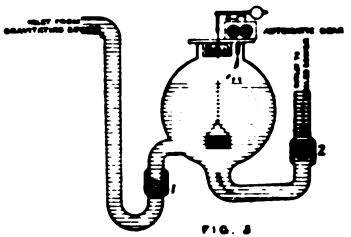


FIG. 3

DISCHARGING

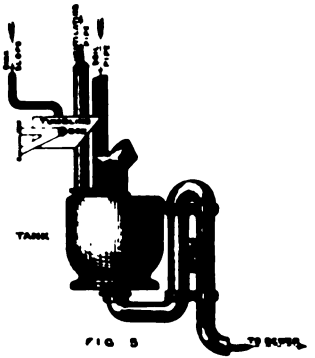


FIG. 5

SHONE'S HYDRAULIC SYPHON EJECTOR

PLATE XII.

is somewhere between thirty and thirty-eight per cent of the power expended in compressing the air, the remainder, viz., from sixty-two to seventy per cent, being lost."* When working at lower pressure the loss is not so great. The pressure needed depends upon the height to which the sewage must be raised. "In using this system, therefore, it may often be better to lift the sewage two or three times successively rather than to do it all at once. Such a course would involve a certain additional cost in multiplying the number of ejectors and in extending the pipes containing compressed air to the additional stations. The amount to be thus expended would, of course, depend entirely upon local circumstances."*

The ejector of Mr. Shone utilizes the power of the compressed air to the best advantage possible when expansion is not used, since the air operates directly upon the sewage without the intervention of a piston or any moving mechanism producing friction, except the valves controlling the flow of the sewage.

The sanitary defects, if any, existing in the Shone system, are those peculiar to the water-carriage system, and do not arise from its peculiar method of pumping. Its tendency is to remove these defects by insuring a rapid flow throughout the sewers. Moreover, when once the sewage has entered the ejectors, there is no longer any danger to be apprehended from sewer gases, as the sewage passes from the ejectors either into sealed pipes under pressure, or into gravity sewers of good declivity.

The Shone system was first brought to the attention of the public in 1878, by the inventor, in an address before the Sanitary Institute of Great Britain. It is in successful operation in several places in England.

* Sanitary Engineer, Vol. 4, 1881.

THE WATER-CARRIAGE SYSTEM.

SEWAGE AND RAINFALL.

The water-carriage system, as the name implies, depends upon the transporting and cleansing properties of water for the removal of sewage. The system is the one that has been adopted for the greater number of sewerage works; indeed the word *sewerage* is sometimes defined as meaning a system of channels for the removal of sewage by this method.

This system is not restricted to the removal of any specific class of sewage, but is used for the removal of house sewage, the surface storm water, the subsoil water, and such liquid wastes from manufacturing establishments as it is proper to admit into sewers. It may, consequently, be adapted to a great variety of circumstances and conditions, which fact has led to its extensive use in this and other countries.

An efficient system of sewers should convey all the sewage away from inhabited districts before any decomposition has taken place in it. The sewers should be so ventilated that the gases contained in them shall have no access to the interiors of buildings.

The first condition is provided for in the water-carriage system by giving the sewers such an inclination that the sewage may flow with sufficient velocity to remove the solid matters suspended in it, and by giving them such transverse dimensions that the stream of sewage shall be concentrated, thereby economizing its scouring power and preventing the stranding of solids along their interior.

According to the experiments of Thos. E. Blackwell, C. E., on the effect of different velocities in removing solid bodies, made in 1857 for the Metropolitan Drainage Referees, "a velocity of from two feet to two and a half feet per second will remove all objects of the nature and dimensions of those that

are likely to be found in sewers." A mean velocity of one yard, or one meter, per second is generally sufficient to prevent deposits in sewers.

The velocity of flow is dependent upon several conditions, the most important being the slope, or inclination of the surface of the liquid. This, except on very flat grades, is sensibly the same as the inclination of the bottom of the sewer itself.

Another condition affecting the velocity is the degree of concentration of the stream; the greater the concentration, the less will be the relative surface of contact between the sewage and the sewer, and, consequently, the frictional resistance.

Another condition that sometimes affects the velocity in the sewer is the velocity with which the sewage enters it. This initial velocity, under certain favorable circumstances, may continue in the sewer, and may accelerate the velocity of flow beyond the amount usually found in sewers of like size and inclination. Instances of high initial velocity are frequently found in the discharges from rain-water leaders, and from catch-basins if considerably above the sewer.

The accelerating effect of high initial velocities cannot, however, be depended upon. Wherever there is the least tendency to stoppage or to an interference of the various entering streams, either with themselves or with the main current, a retardation ensues which causes the sewer to become choked and to discharge, under pressure, through the nearest available outlets; flooding cellars and, in extreme cases, overflowing upon the surface of the street.

Before determining the sizes of sewers, it is necessary to ascertain the volume of sewage that they will have to carry. In dealing with this element of the problem, a great diversity in practice has arisen, resulting in two distinct types of water-carriage sewerage, called respectively the "separate" and the "combined" systems. By the first, the house sewage and other waste liquids, with or without a limited portion of the storm water, are conveyed in one distinct system of sewers, the surface and subsoil waters being conveyed in other distinct systems. By the second, a single system of channels is provided for the conveyance of all matters.

The amount of sewage derived from the drainage of houses, public institutions, and manufacturing establishments may be taken as approximately equal to the water supply, the greater portion of which, after use, passes away through the sewers. It is important to remember, however, that this class of sewage is not discharged into the sewers at a uniform rate, but that its volume varies from hour to hour, and depends largely upon the domestic habits of the population. It was found in London that the maximum flow in the more fashionable districts of the west end occurred two or three hours later than in the districts at the east end occupied by the poorer classes.*

Careful observations upon the flow of the London sewers showed that if the day be divided into three periods of eight hours each, the amount of the maximum flow was during the eight hours between 9 A. M. and 5 P. M., and was equal to forty-nine per cent of the entire daily flow, while eighteen per cent only flowed during the eight hours of minium flow, which occurred between 11 P. M. and 7 A. M.†

In estimating the maximum quantity of sewage likely to enter the sewers at various parts of the metropolis, a liberal margin was taken beyond the results of actual measurements, and provision was made for one half of the sewage to flow off within six hours.*

These rates have each been used in other instances as general guides in estimating the ordinary maximum flow of sewers.

When large volumes of subsoil water are constantly entering the sewers, the conditions become somewhat different and the flow becomes more uniform throughout the twenty-four hours.

The maximum daily flow of sewage is not an important factor in determining the sizes of sewers belonging to the combined system, their size depending upon the volume of storm water which they will have to carry. It is, however, an important factor in determining their shape, which should be such as will concentrate the small stream of ordinary sewage as much as is practicable.

In the sewers of the separate system, from which the storm

* Bazalgette, The Main Drainage of London.

† Metropolitan Main Drainage Report, 1857.

water is excluded, the maximum daily flow becomes an important factor in determining the size.

Careful observations upon the hourly flow of the sewers of Memphis, Tenn., which is sewered upon the separate system, show it to be remarkably uniform. "Thus, from 6 A. M. till 1 A. M. the following morning, a period of twenty hours, the flow oscillated in centre depth from 12.5 to 14.5 inches; the minimum area of flow being 206.5 square inches, the maximum, 245.73 square inches. From 1 A. M. until 5 A. M., a period of four hours, the centre depth of flow varied from 8.5 inches to 11.5 inches; minimum area being 107.6 square inches, maximum area, 186.9 square inches. Taking the twenty-four hours, the minimum flow is 43.7 per cent of the maximum; taking the twenty hours of greatest flow, the minimum is eighty-four per cent of the maximum. Eight ninths of the daily flow of sewage passed in twenty hours; one ninth in four hours. This marked uniformity of flow during twenty hours of the day, and its oscillating character within such small limits, must be somewhat influenced by the action of the flush-tanks, which probably discharge in small groups."*

An example of the variations in the flow of sewers receiving subsoil water is given in the Fourth Annual Report of the Massachusetts State Board of Health, 1873. An examination of the ordinary flow of sewage in the sewers of Worcester, Mass., showed that, taking the twenty-four hours, the minimum daily flow varied from fifty per cent to eighty-nine per cent of the maximum daily flow, and "that the flow from 9 P. M. to 6 A. M. is about eight ninths of the flow from 9 A. M. to 6 P. M."†

The amount of storm water to be provided for depends upon several conditions, which vary so much in different localities that no general rules can be given for the calculation of the precise amount of storm water in any given place. These conditions are, —

1. The amount of rainfall in a given time, as one hour, and the duration of the rain.
2. The permeability of the surface of the ground.

* Latrobe, Baltimore Sewerage Report, 1881.

† For results of gaugings of Providence sewers, see Appendix C.

3. The degree of saturation of the ground at the period of rain, the season of the year, and the amount of evaporation.
4. The character and inclination of the surface of the ground.

In observing the rainfall, great care should be exercised to ascertain the precise duration of the entire storm, also the duration of the heavy showers that frequently occur during storms, and the amount of rain falling at these several periods. This may be done most conveniently by an automatic self-recording rain-gauge, by means of which the rate of fall at any instant during a storm may be ascertained. Meteorological records should be used with great discrimination, in computing rates of rainfall. Unless the observations have been made for the express purpose of obtaining them, the rates of fall derived can seldom be depended upon. These records, as usually made, merely give the total amount of rain falling at certain times, and fail to distinguish, for example, between a fall of one inch within an hour, and another of one inch which is an hour in falling. Had the former occupied only twenty minutes, the rate of fall would have been three inches per hour.

If all the storm water is to be conveyed by the sewers, provision should be made for conveying such a quantity as is likely to be occasioned by severe storms, even if such storms occur at comparatively long intervals; for a system of sewers should at no time be the source of damage to property or health through failure to perform its functions. Should these conditions require excessive sizes and cost, — and they usually will, — no attempt should be made to convey the entire volume of the water of severe storms through the sewers, but portions should be allowed to flow over the surface of the streets, or should be conveyed by special channels.

The discharge of surface water from very large drainage areas presents a peculiarity which should be remembered when proportioning the sizes of the main out-fall sewers of very large districts: it is, that the parts of the district lying nearest the channel of discharge will have delivered a portion of storm water before other portions from the more distant parts will

have had time to reach the channel by flowing over the surface of the ground. Under these circumstances, the channel of discharge may be made smaller than would be necessary were all parts of the district discharging into it simultaneously. There is an important limitation, however, to the application of this principle.

"When water falls in the shape of rain on any solid surface, whence it afterwards flows off, it forms its own drainage vehicle. It produces over that solid surface a certain depth of water with a certain superficial slope or fall toward an outlet; these two conditions, depth and surface slope, being necessary to produce flow. Should the solid surface be at all absorbent, the rain has to furnish the quantity of water necessary to saturate it. While the drainage vehicle is forming and having its capacity increased, the water is flowing off the surface less rapidly than it falls upon it, and, should the rain cease before it has completed its own drainage vehicle, the rate of discharge from the surface upon which it falls will never equal the rate at which the rain has fallen upon it. It is only when the time necessary for this preliminary operation of forming its own drainage vehicle has elapsed, that the water flows off from a surface as rapidly as it falls upon it. The time required increases with the linear distance between the upper and lower ends of the surface drained and with the gentleness of its fall."*

Assuming that the drainage vehicle has been sufficiently formed to produce a flow over the entire surface of a drainage district, a particle starting at the distant periphery of the district will, in due time, arrive at the channel of discharge. Should the rain continue until this occurs, this particle from the periphery will have united with a series of other particles at successive points, and the entire elementary discharge will be equivalent to a simultaneous discharge into the channel from all points of the path of flow. The conditions being the same for other paths, the total discharge of the drainage district will be equivalent to the simultaneous discharge from all its parts, whenever the rain continues (after having formed the drainage

*O'Connell, Flood Discharge of Rivers, Proc. Inst. C. E., Vol. 27.

vehicle), until a particle from the farthest point of the periphery shall have reached the channel of discharge. This tendency to flood will continue until the rain ceases.

Where the drainage district is small and the surface comparatively impervious, the time required to form the drainage vehicle is very short. Where the communication between the periphery of the district and the main outfall channel is direct and the flow rapid, the time required for a particle to traverse the distance will also be short. These conditions exist pre-eminently in city drainage areas. Consequently the duration of ordinary storms very frequently exceeds the time required to establish the conditions producing floods in the sewers of cities, particularly in districts that are thoroughly sewered, and in which the storm water is admitted to the sewers near the periphery of the district.

In very large districts comprising a large proportion of suburban area covered with gardens and lawns, where the storm water has to flow over the surface for considerable distances before reaching the sewers, the duration of storms may seldom be sufficient to establish the conditions of flood, and the discharge of the storm water from contiguous zones of such drainage districts may usually be considered as consecutive; but in urban districts comprising paved streets and yards, where the storm water is led directly to the sewers, the discharge will often be simultaneous from all parts of the drainage district.

The principle of reducing the sizes of main sewers on account of the successive discharge of storm water from contiguous zones of the drainage district should, therefore, be very cautiously applied.

The flow of storm water into storage reservoirs is in some respects similar to the flow into the sewers of suburban districts. Observations made upon the amount of water received into the storage reservoir of the water works at Nagpoor, India, from some extraordinary showers during the monsoon of 1872, show the marked influence of the degree of saturation of the soil at the time of the rainfall upon the amount discharged from the catchment basin. The reservoir received the drainage from a water-shed of 4,224 acres, or 6.6 square miles. The details of these observations, given in the following table, are from a

paper on the Nagpoor Water Works, by A. R. Binnie, M. Inst. C. E.*

EXTRAORDINARY SHOWERS AT NAGPOOR DURING THE MONSOON OF 1872.

Dates.	Rainfall.			Rise of Water in Reservoir, etc.		
	Amount.	Duration.	Rate of fall per hour.	Rise of water in Reservoir.	Duration.	Proportions of rain flowing from the whole Drainage area.
1872.	Inches.	H. M.	Inches.	Feet.	H. M.	
June 18	2.24	1 20	1.684	. . .	. . . .	. . . .
July 3	3.92	24	0.163	1.50	24	0.160
July 10	0.71	20	2.131	0.32	3	0.204
July 12	1.26	30	2.520	1.00	3	0.392
Aug. 9	0.97	1 30	0.646	0.10	2	0.065
Aug. 10	3.50	1 45	2.000	3.15	3	0 607
Aug. 24	1.00	40	1.515	0.60	3	0.510
Sept. 7	0.60	1	0.600	0.60	5 30	0.940
Sept. 16	0.50	30	1.000	0 40	6	0.760
	2.20	1 20	1 650	2.20	2 50	0.983
Oct. 6	0.50	20	1.500	1.34	3	0.346
	3.55	45	4.733			

"These showers produced a flow varying from almost nothing in the case of the shower of 2.24 inches in one hour and twenty minutes on the 18th of June, up to a discharge of 33,160,380 cubic feet, due to a fall of 2.20 inches in one hour and twenty minutes on the 16th of September. These facts prove to what an extreme state of dryness the soil in India is reduced at the end of the hot season, and how saturated it becomes after heavy rain late in the monsoon. In the last column of the table is given the proportion of the rainfall of the various showers which flowed from the ground in the times noted in column 6. From this it will be seen that, of the 2.2 inches on the 16th of September, ninety-eight per cent entered the reservoir within two hours and fifty minutes."

The rainfall here referred to followed a fall of 0.5 inch on the same day, of which only seventy-six per cent was observed to have entered the reservoir; the second rainfall, consequently,

* Proc. Inst. C. E., Vol. 39, 1874–5.

fell upon a surface already moist, and the preparation of its drainage vehicle absorbed but a small percentage of its volume. The rainfalls of the 6th of October, after an interval of about three weeks, only discharged about thirty-five per cent of their joint volume into the reservoir, owing probably to the altered condition of the soil after that interval of time.

Owing to the indeterminate nature of the problem, it has become customary to assume that one half the volume of a given rainfall will reach the sewers during the time of fall. For example, it is customary to assume that the volume discharged into the sewers from a rainfall of one inch per hour will be equivalent to a depth of half an inch per hour over the entire area of small drainage districts. This is equivalent to a discharge of 30.25 cubic feet per minute per acre, or 0.5042 cubic feet per second per acre.

Several attempts have been made to recognize, in mathematical form, the variation in the discharge per unit of drainage area in districts of different sizes, occasioned by the greater time necessary to form the drainage vehicle on large districts, and also by the successive discharge from their contiguous zones.

The best formula at present known for estimating the probable amount of storm water to be provided for is that of Mr. Burkli-Ziegler, which is given by Mr. Rudolph Hering in his valuable report to the National Board of Health, upon the results of an examination made in 1880, of several sewerage works in Europe. This formula is

$$Q = c\, r \sqrt[4]{\frac{s}{A}},$$ in which,

Q = quantity of water reaching the sewers, in liters per hektare per second.

c = coefficient depending upon the nature of the surface, and ranging from 0.25 for rural districts and suburbs, to 0.60 for paved streets and roofs. Its ordinary value is 0.50.

r = the average intensity of the rain during the period of the heaviest fall, in liters per hektare per second.

s = general grade of the drainage area per 1,000.

A = area drained in hektares.

When Q and r are given in cubic feet per second per acre, and A is given in acres, the formula becomes

$$Q = 1.25\ c\ r\ \sqrt[4]{\frac{1}{A}}$$

"The tendency of this formula is to give amounts which increase as the rain becomes heavier, as the slope increases, and as the surface becomes less penetrable by the water. On the other hand, they decrease as the area becomes larger."

"It was derived from observations on the intensity of some heavy storms, and the corresponding discharge of sewers in Zurich, together with information obtained from other European localities. The range of observations was limited to comparatively small areas, and included some of the heaviest known rainfalls. The slopes of the areas extended to ten feet per hundred. The values of r, which he recommends for Switzerland and Central Europe, correspond to an average intensity of 1.75 to 2.75 inches per hour, depending on how far provision is deemed expedient for extraordinary storms."

"The principle which the formula embodies is to give to the fraction of the rainfall which enters sewers a decreasing proportion per acre per second for an increasing size of the drainage area, a fact which in general has long been recognized."*

Acres drained.	Proportion, $\frac{Q}{r}$, of Rainfall flowing off.					Acres drained.	Proportion, $\frac{Q}{r}$, of Rainfall flowing off.				
	Surface, 5 per 1,000.	Surface, 10 per 1,000.	Surface, 20 per 1,000.	Surface, 50 per 1,000.	Surface, 100 per 1,000.		Surface, 5 per 1,000.	Surface, 10 per 1,000.	Surface, 20 per 1,000.	Surface, 50 per 1,000.	Surface, 100 per 1,000.
20	0.44	0 53	0.62	0.79	0.93	1,500	0.15	0.18	0.21	0 27	0.32
50	0.35	0.42	0.50	0.62	0.74	2,000	0.14	0.17	0.20	0.25	0.30
100	0.30	0.35	0.42	0.53	0.62	3,000	0.13	0.15	0.18	0.22	0.27
150	0.27	0.32	0.38	0.47	0.56	5,000	0.11	0.13	0.16	0.20	0.24
200	0.25	0.30	0.35	0.44	0.53	7,000	0.10	0.12	0.14	0.18	0.22
300	0.22	0.27	0.32	0.40	0.47	10,000	0.09	0.11	0.13	0.17	0 20
500	0.20	0 24	0.28	0.35	0.42	15.000	0.08	0.10	0.12	0.15	0.18
700	0.18	0.22	0.26	0.32	0.38	20,000	0.08	0.09	0.11	0.14	0.17
1,000	0.17	0.20	0.24	0.30	0.35	30,000	0.07	0.08	0.10	0 13	0.15

The above table gives the proportion $\frac{Q}{r}$ of the rainfall which may be expected to flow from districts of various sizes accord-

*R. Hering, Trans. Am. Soc. C. E., November, 1881.

ing to this formula; the coefficient c being taken at its mean value, 0.50, and the inclination of the surface of the district being taken at 5, 10, 20, 50, and 100 per 1,000, as indicated in the several columns of the table.

The probable amount of storm water to be provided for in the construction of a system of sewers cannot at present be estimated with exactness: such an estimate must depend largely upon experience and judgment, and existing formulas must be considered merely as aids to correct judgment, and not as possessing mathematical exactness.

The amount of sewage to be removed at different parts of the drainage district having been determined, the sizes of the sewers may be computed by means of any reliable hydraulic formula, of which the one known as "Kutter's formula" is at present considered to be best adapted to the solution of problems connected with the sewerage of cities, and is the one now in use in this city.

The sizes of sewers are often dependent upon financial instead of meteorological conditions. When, for instance, the sewage has to be pumped from low lying districts to a higher elevation before it can flow to the outfall, the expense of establishing and maintaining sufficient pumping capacity, in excess of the ordinary amount, to remove the water from severe storms, becomes enormous, and, together with the excessive cost of constructing sewers of sufficient size, renders the scheme impracticable. In such cases it is usual to convey to the pumping station only a portion of the storm water, the remainder either flowing over the surface of the streets, or, if admitted into the subsidiary sewers, being excluded from the main sewer leading to the pumping station, and allowed to pass into other channels through overflow weirs.

At London, where this arrangement is adopted, storm water only to the amount of one quarter inch in depth per twenty-four hours from urban territory, and one eighth inch in depth per twenty-four hours from outlying suburban territory, nearly equivalent to 0.01 and 0.005 of an inch per hour respectively, is carried to the outfall, in addition to the ordinary daily sewage, during the six hours of maximum daily flow. Greater rainfalls

than this frequently occur in London, and overflows have been provided, through which an excess of water may pass into the Thames.

The new sewerage works at Boston, Mass., are designed to convey 0.01 of an inch of rain-water per hour to the outfall, in addition to the daily sewage, when flowing about half full, and numerous overflows have been provided by which surplus water can pass directly into the harbor through the old outlets.*

The following table, compiled from Mr. Hering's report on European sewerage works, shows in a general way the extent to which storm water has been provided for in the sewers of some of the more important European cities. It indicates the great diversity caused by various local conditions.

Place.	Maximum rainfall known.	Maximum rainfall recognized.	Proportion supposed to enter sewers.	Rainfall provided for in sewers.	Remarks.
	Inches per hour.	Inches per hour.		Inches per hour.	
Paris	4.8	1.77	$\frac{1}{3}$	0.590	All sewers are large enough for men to walk upright in them. The rainfall is only considered when the grades are small.
Berlin	2.3	$\frac{1}{3}$	$\frac{1}{3}$	0.292	
Vienna	1.0	1.+	About $\frac{1}{3}$	0.375	All sewers are large enough to be entered. The estimated storm flow when used to determine size only fills the sewers to the springing line of the arch.
Hamburg	1.1	$\frac{1}{24}$	$\frac{1}{3}$	0.028	All ordinary sewers are large enough to be walked through. The storm flow is mainly considered in connection with the intercepting sewers. Numerous overflows are provided.
Frankfort	1.2	$\frac{1}{48}$	All	0.021	For the intercepting sewers only.
Frankfort	1.2	$\frac{1}{4}$	All	0.250	For certain overflow sewers.
Dantzic		$\frac{1}{24}$	All	0.042	Numerous overflows are provided.
Brighton	0.7	$\frac{1}{2}$	All	0.500	

The relation between the storm flow of sewers and their ordinary daily flow is necessarily very variable.

* Clarke, Main Drainage Works at Boston.

The following table, by Sir J. W. Bazalgette,* shows the results of some observations upon the flow of the London sewers.

TABLE SHOWING APPROXIMATELY THE DIFFERENCE BETWEEN THE ORDINARY FLOW IN THE SEWERS IN DRY WEATHER AND DURING HEAVY STORMS.

Number of Section.	Points at which Observations were taken.	Dimensions of Sewer.	Approximate inclination.	Depth of flow during		Relative proportions of ordinary flow to storm discharge.
				Dry weather.	Storms.	
1	Ranelagh Sewer, Gloucester Road.	8′ 6″ x 10′ 6″	One in. 563	Ft. In. 1 1½	Ft. In. 7 6	One in. 21.5
2	Fleet Sewer, Kentish Town Road.	6′ 6″ x 6′ 0″	316	9	5 1½	26.
3	Hackney Brook Sewer, Dalston Road.	5′ 0″ diam.	350	6½	2 9	19.
4	Sewer at intersection of New North Road and Murray St.	5′ 0″ x 3′ 6″	350	9	5 0	17.†
5	Cockspur St. (Northumberland St. Sewer).	5′ 6″ x 3′ 0″	108	8¾	4 0	10.5
6	Bow St. Covent Garden.	5′ 6″ x 3′ 0″	193	6½	4 7	21.
7	Green Park (Pall Mall Sewer).	6′ 0″ x 4′ 0″	503	9¼	4 0	11.
8	Effra Sewer, Vassal Road, Brixton.	9′ 2″ x 11′ 0″	302	7	4 6	24.

The drainage of the subsoil water is usually effected by sewers in an indirect manner. Occasionally, when the volume of subsoil water is very great, separate lines of agricultural drain-pipes are laid beneath or beside the sewers. They may discharge the subsoil water into the sewers at convenient points, or may lead it to other channels.

Frequently, no special provision is required for the disposal of the subsoil water. The mere opening of sewer trenches exerts a powerful influence towards the drainage of retentive soils, by breaking up the strata and natural lines of underground flow, and presenting new channels for the flow of subsoil water through the earth which is refilled into the trenches, which is seldom as compact as it was originally. Although

* Met. Main Drainage Report, 1857.

† This sewer is often discharging under pressure.

sewers are expected to be water-tight, and are carefully constructed with that object in view, there exist, nevertheless, in the best constructed sewers, some points where the subsoil water may enter them, either through the porous substance of the sewers themselves or at certain joints.

This, although undoubtedly a defect, has been found to cause no serious pollution of the soil from the percolation of sewage. The ground water is seldom removed so completely as to permit this reverse percolation. Usually it remains at a somewhat higher level than the ordinary line of flow in the sewer, and controls the direction of the percolation by its superior pressure.

* "In Munich, Pettenkofer has continued his researches on the pollution of the soil, and has finally shown, as already proved by Lindley, that well-built sewers do not allow soluble organic matter to escape into the ground to any serious extent, although they act as drains in relieving the soil of its moisture."

"Dr. Wolfhügel has also proved this fact, by careful analysis of the soil in different places, as is shown in the following table:"—

TABLE SHOWING THE COMPARATIVE POLLUTION OF THE SOIL FROM SEWERS, CESSPOOLS, AND PRIVY VAULTS, AS GIVEN BY DR. MED. GUSTAV WOLFHUGEL.

(*Results expressed in kilograms to the cubic meter of earth.*)

Composition of Earth.		Normal earth.	Average of earth under 8 sewers.	Average of earth under 8 cesspools.	Earth 4.5 meters (14.76 ft.) from a privy vault.
Depth in meters at which analyses were made		3.7	†	2.4‡	2.3
Soluble Constituents	Residue on evaporation	0.211	0.217	0.603	4.710
	Loss on ignition	0.052	0.091	0.185	1.500
	Organic substances	0.118	0.093	1.257	2.230
	Chlorine	0.010	0.021	0.110	0.330
	Nitric acid	0.012	0.018	0.019	0.460
Insoluble.	Loss on ignition	1.504	3.356	5.461	39.772
	Nitrogen	0.014	0.055	0.060	0.956

* Seventh Annual Report, Massachusetts Board of Health, 1876, p. 309.

† Directly under the sewers. ‡ Directly under the cesspools.

"By digging underneath well-built sewers, Dr. Wolfhügel showed experimentally to a large number of experts that the soil was not appreciably affected by the sewage."

THE SHAPE AND SIZE OF SEWERS.

The correctness of the principles given in the previous section as governing the self-cleansing action of sewers has been abundantly proved by numerous examples from the practice of former days.

One does not need to search far among the works built according to the principles in vogue in this country twenty-five or thirty years ago, to find examples of sewers constructed of stones or bricks laid without mortar or in common lime, through whose open or imperfectly filled joints the sewage water escaped into the surrounding earth, filling it with pollution, leaving the solid matters to accumulate in the sewers, from the want of sufficient liquid to carry them to the outfall. Neither is it difficult to find examples of sewers whose dimensions were so excessive, compared with the quantity of sewage to be conveyed, that the ordinary stream of sewage was spread over broad surfaces, its scouring power being expended in forcing a tortuous passage through deposits and among obstructions.

In those days, a self-cleansing sewer was rare indeed. Deposits were expected in sewers, and their sizes were made such that they could be entered and cleaned by manual labor whenever occasion required.

It was felt in England, at an earlier period than in this country, that such methods must be radically wrong, since the sewers failed to accomplish the purpose for which they were built, and acted as reservoirs for the retention of filth, instead of channels for its speedy removal.

This subject was very fully examined by the Metropolitan Sanitary Commission, and their first report, made in 1847, contains many examples of the inefficiency of prevailing methods of sewer construction, as well as suggestions foreshadowing methods now in use.

Mr. John Phillips, C. E., chief surveyor to the Westminster Court of Sewers, stated in his evidence before this commission: —

"I had observed, in passing through them (the sewers), that a large number of them had a tendency to choke up, inasmuch as not only was the flatness of the bottom unfavorable to the free flow, but there was the escape of drainage from passing through the open joints of the bottoms."

This statement was accompanied by several sectional sketches showing the sewer, the house drain, and several typical forms of deposits as observed in the sewers. These are shown on Plate 13, Figs. 1, 2, 3, and 4.

Concerning the means of correcting this tendency of the sewers to become choked with deposits, Mr. Phillips testified: —

"I take my data from practical experience and observation rather than from theory or calculation. In passing through the sewers, I have observed that the currents of water running through very many of the branch and collateral sewers were mere dribbles, and that, from being diffused over a large, flat surface, they were not of sufficient strength to remove the soil. Looking at these currents and comparing them with the extraordinary sizes of the sewers (Plate 13, Figs. 6 and 7), I should say such currents might be passed through pipes varying from three to nine inches in diameter. In a large number of the sewers, the currents have cut narrow and deep channels through the soil (Plate 13, Fig. 2), and by so doing, it appeared to me that nature was endeavoring to correct the faults of art. I think it would be desirable to take a lesson from nature in this respect, and form the bottoms of all the sewers which have a tendency to choke up in accordance with the following sketch (Plate 13, Fig. 5). It has sometimes been the practice to cut similar channels through the soil for the drainage to run through, and they have acted for a time very well indeed, so well as to give me entire confidence in the working of narrow and reduced sizes of sewers. I propose to bed channel-tiles of various diameters along the bottoms of the sewers, and fill in behind them with concrete. I am satisfied that . . . most of the sewers would keep themselves clean by this means."

The transition from this modified form for the improvement of faulty existing sewers, to an egg-shaped section, for the

construction of new sewers, was both easy and natural. Three forms of egg-shaped sewers, designed by Mr. John Phillips, are shown on Plate 13, Figs. 8, 9, and 10. The form shown in Fig. 8 has been very extensively used, and is the form adopted for many of the Providence sewers. Fig. 9 is given in the report above referred to. The lower part is the same as in Fig. 8, but the upper part is modified to give more height for a given width. Fig. 10 is a more recent design. Mr. Baldwin Latham writes concerning it:* "The new form (Fig. 10) is stronger than the old form (Fig. 8), and, under certain conditions of small volumes of flow, it is better adapted to be a self-cleansing sewer than the old form of oval sewer. . . . In the new form, as a given volume of sewage will fill the sewer to a greater vertical height than in the old form, it is consequently found that, with moderate quantities of sewage flowing in the sewers, there is a greater surface fall and velocity of flow in the new form than in the old form of sewer." Another design, composed of the upper portion of Fig. 9 combined with the lower portion of Fig. 10, was used by Mr. Latham in a tunnel sewer under the town of Longton.

The proportions used in drawing these forms for egg-shaped sewers are given in the following table: —

THE DIMENSIONS OF EGG-SHAPED SEWERS IN TERMS OF THE TRANSVERSE DIAMETER, A B.

Line.	Figure 8.	Figure 9.	Figure 10.
c d	1½	1⅝	1½
c h	¼	¼	¼
a f	1½	1½	1½
c i	1	1	1
i d	½	⅝	½
i l	. . . .	¼	. . . .
a j	. . . .	⅛	. . . .
k m	. . . .	5/16	. . . .
l m	. . . .	7/16	. . . .

Egg-shaped sewers are adapted to cases where great variations occur in the volume of sewage. The bottom of the sewer,

* Sanitary Engineering, p. 180.

PLATE XIII

Fig. 1.
Fig. 2
Fig. 3.
Fig. 4
Fig. 5.
Fig. 6.
Fig. 7.
Fig. 8
Fig. 9.
Fig. 10
A. LEVEL OF ORDINARY FLOW
B. " " FLOW IN GREATEST THUNDER STORM
C. " " DURING GREATEST STORMS
SECTIONS OF LONDON SEWERS

being sharply curved, concentrates the stream of dry-weather sewage, thereby preserving its scouring power and rendering the sewer self-cleansing during dry weather, if its size has been properly adapted to the local conditions. The upper part of the sewer, being of greater size, furnishes capacity for large quantities of storm water.

When the volume of sewage is more uniform, the circular form is better adapted to the conditions of flow. Of all plane figures enclosing the same area, the circle has the shortest periphery. A sewer flowing constantly full should therefore be circular, since it then presents the least amount of frictional surface. The proportion between the area and periphery of a semicircle being the same as for the full circle, it follows that sewers which are to flow constantly half full should be circular. The circular form is also the strongest and cheapest to build.

When the conditions of flow in sewers are such that the ordinary flow is considerable in volume, while the storm flow is so controlled that it is not more than double the ordinary flow, the circular form should be adopted. These conditions frequently exist in the main lines of sewerage. Intercepting and outfall sewers are consequently made of circular form in numerous instances.

The smaller sizes of sewers can be made more cheaply and satisfactorily with pipes than with bricks. Glazed pipes present very little frictional resistance to the flow. A proper scouring velocity can, consequently, be obtained with an inferior concentration of the stream. It is, therefore, customary to use the circular form for small sewers of glazed pipes.

The size at which the cost remains the same whether pipes or bricks are used depends upon the relative cost of materials and labor, but this economic limit is usually found in sewers of sixteen or eighteen inches diameter. It may therefore be said, in a general way, that sewers less than sixteen or eighteen inches in diameter are usually made of circular, glazed pipes, and that sewers greater than sixteen or eighteen inches in diameter are usually made of brick, and egg shaped, except intercepting and outfall sewers, which are frequently made circular.

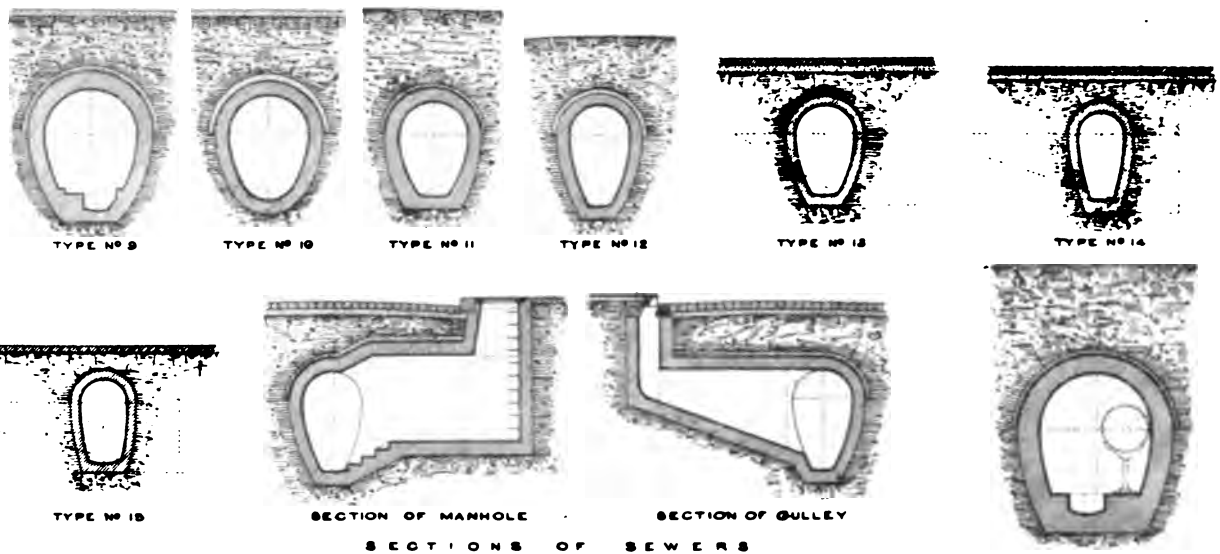
Other forms are sometimes required where sufficient depth is wanting to construct egg-shaped and circular sewers. These forms should be adapted to the local requirements, and to the peculiar conditions of earth pressure existing at the places where they are to be built.

The sizes and forms of the sewers of some European cities have been based upon principles different from those governing the proportions of self-cleansing sewers. The sewers of Paris, for example, are noted for their enormous size and completeness of construction. The French engineers assumed that it would be necessary to remove deposits from all their sewers by manual labor, that they must consequently be of sufficient size to be entered, and that a true regard for economy would require that their sizes should be such that men could work in them without being cramped for want of room.

These sewers are intended to receive the surface water from the streets, — that coming from storms as well as that used in the daily washings of the streets, — the overflow from cesspools and the sink water. No solid fæcal matter was allowed to enter them until recently. It is now permitted to enter certain sewers in which the current is sufficient to prevent deposits. The openings in the gutters are connected directly with the sewers without any intervening catch-basin or trap. All the street detritus thus passes into the sewers, from which it is removed with great labor and expense, by workmen who are constantly employed for this purpose.

Some of the forms of the Paris sewers are shown on Plates 14 and 15.* That adopted for the larger sewers recalls the design suggested in 1847, by Mr. Phillips, Plate 13, Fig. 5. The lower channel or *cunette* is for the ordinary stream of sewage. The upper portion, made large for the convenience of the workmen, provides capacity for excessive storms. They are provided with a footpath (*banquette*) upon each side. Some of them have a railway track, upon which the workmen run small wagons containing tools and other apparatus; others are navigated by boats. Water pipes are laid in the upper por-

* Proc. Inst. C. E., Vol. 53.



SECTIONS OF SEWERS
IN USE IN PARIS

PLATE XIV

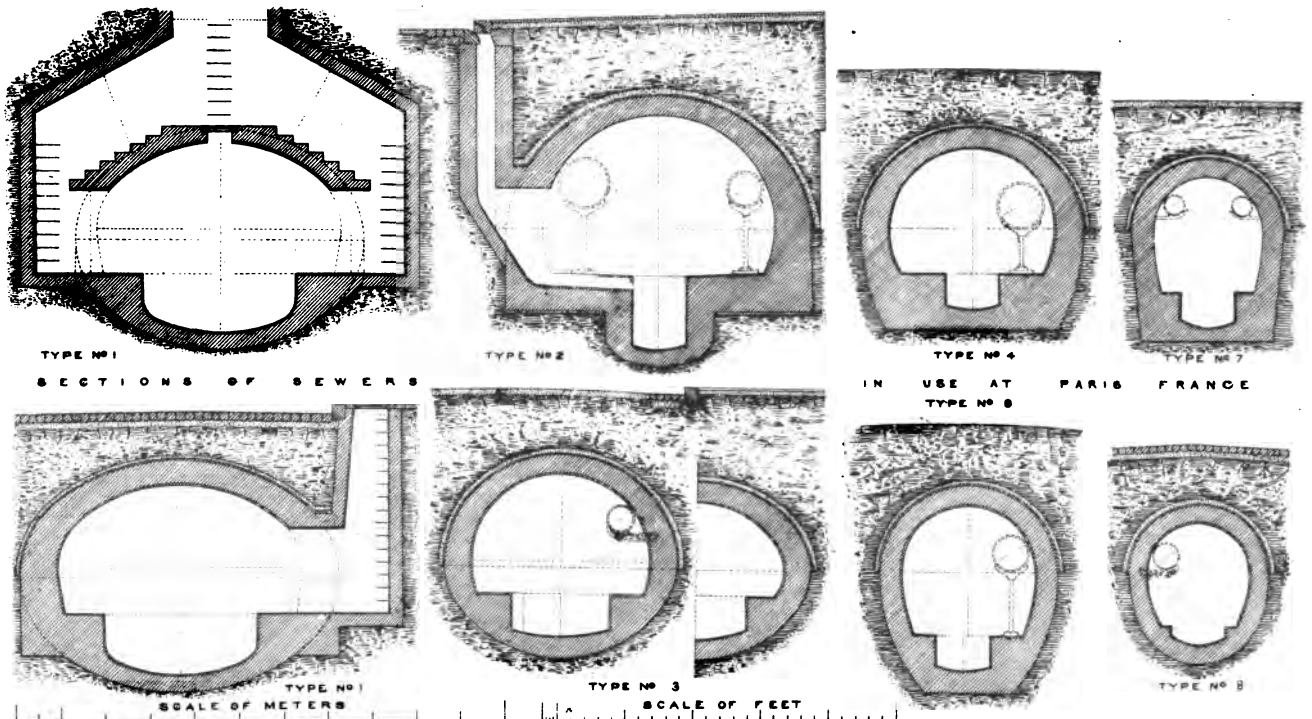
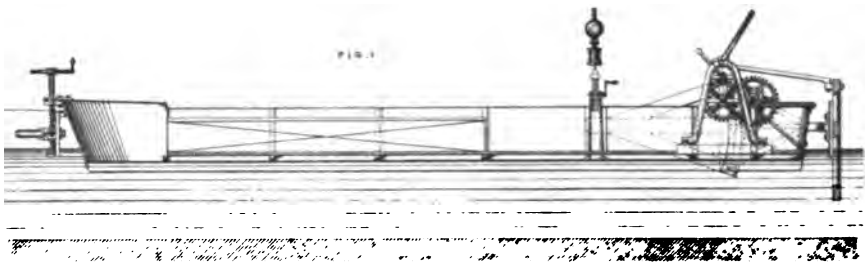
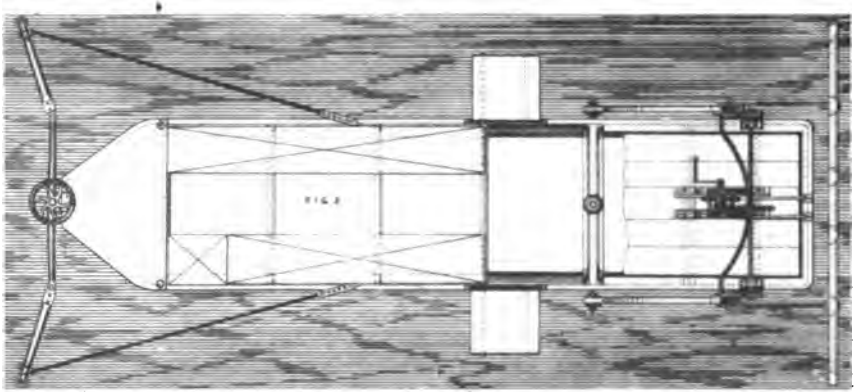
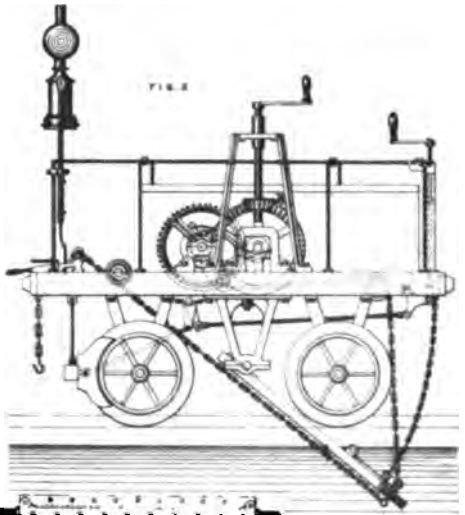

TYPE Nº 1
TYPE Nº 2
TYPE Nº 4
TYPE Nº 7
SECTIONS OF SEWERS IN USE AT PARIS FRANCE
TYPE Nº 8
TYPE Nº 1
TYPE Nº 3
TYPE Nº 8
SCALE OF METERS
SCALE OF FEET

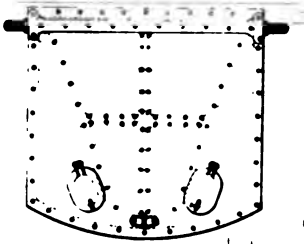
PLATE XV



FLUSHING BOAT







FLUSHING TRUCK

FLUSHING BOAT AND TRUCK USED IN PARIS SEWERS

PLATE XVI

tions of these sewers, for convenience of access, and to avoid opening the streets during repairs.

The cleaning of the large sewers is done by travelling dams. These are formed so as to fit the lower channel (*cunette*) of the sewer. They are attached to the boats and wagons by mechanical appliances, by which they may be lowered to any required position (Plate 16). The boat being placed at the up-stream end of the section to be cleaned, the dam (*vanne*) is lowered until its lower edge enters the deposits in the sewer. The sewage thereupon rises back of the dam, creating a pressure which forces a strong current beneath the dam, loosening the deposits. The pressure also moves the boat and dam forward until the resistance of the accumulated deposits becomes too great, when a new start is made.

THE VENTILATION OF SEWERS.

The importance of perfect ventilaton in sewers is second only to the need for the rapid and complete removal of all putrescible matters. It is not necessary to enter into any extended argument to prove the deleterious nature of the gaseous products of decomposition usually found in sewers, and commonly termed sewer gas. It is universally admitted that, when of sufficient strength, these gases may produce debility, loss of appetite, headache and nervous prostration, and may render the system susceptible to the attacks of disease. It is also very generally admitted that they may become the vehicle for conveying the germs of certain contagious diseases, as diphtheria, typhoid fever, scarlet fever, etc. By the processes of ventilation, these gases become diluted with atmospheric air, which greatly modifies their dangerous character.

Thorough ventilation is also necessary to prevent the gases in the sewers from being compressed by any sudden increase in the volume of sewage, as occurs during sudden storms, and whenever the outlets of the sewers are tide-locked, or by the effect of a sudden rise of the temperature within the sewer, which may be caused by the admission of hot water or steam. A very slight degree of pressure is sufficient to overcome the resistance offered by water-seal traps, which are the usual

defence against the entrance of sewer gases into our dwellings. Thus, for example, a pressure of a little more than one ounce per square inch may be sufficient to force a running trap having a water-seal one and one half inches in depth. For this reason, among others, the admission of hot water and steam into sewers should be prohibited. Internal pressure may sometimes be produced by strong winds blowing into the outlets of the sewers. This should be prevented by suitable construction.

But, important as the ventilation of sewers is, from sanitary considerations, no method has yet been found which has given entire satisfaction, nor which is applicable to large cities as a whole. The most general solution of this question is to provide an ample supply of water to cleanse the sewers and to remove all putrescible substances, thereby preventing the formation of noxious gases, and to provide frequent and ample openings to admit fresh air and promote circulation.

The subject of sewer ventilation has received the attention of sanitarians for very many years, and there has been no lack of suggestion of methods, nor of trial of such as seemed most feasible. The difficulties connected with its solution are inherent to the question itself.

Mr. W. Haywood, engineer of the London City Commissioners of Sewers, testified in 1858:* "I have examined the question with the greatest care, and, although I am compelled to state that the present system is very far from a perfect one, yet every proposition for improving the ventilation is met with hosts of difficulties which really look insignificant until you investigate them, when they become so formidable that you may call them invincible."

The motion of the air in sewers is dependent upon conditions which are constantly varying. At times, it is controlled by the friction of the stream of sewage, which may produce a current of air flowing in the same direction. At other times, it is dependent upon the relative densities of the air within and without the sewer. This may cause the sewer air to rise to the

* Report of Select Committee on the State of the River Thames, 1858.

more elevated districts, or the reverse, producing much annoyance from foul odors. Again, the motion of the air may be affected at different points in the same sewer by a variety of conflicting influences, producing counter currents and eddies. Where it is customary to leave the house drains untrapped, and to extend them above the roofs with open ends, thus acting as ventilators to the sewers, the temperature of the air within the house drains and soil pipes, which is dependent upon the temperature of the houses, may become the controlling element governing the direction of the currents in the sewers, and may produce outward or inward currents at the house connections according to the relative temperatures of the air in the houses and in the sewers.*

The direction and velocity of the currents of air in sewers being so variable, the means employed for ventilation must be either sufficiently varied in their character to meet the diverse requirements, or sufficiently energetic to be themselves, at all times, the element governing the direction of the motion of the air throughout the entire system of sewers.

The ventilation of mines is usually accomplished by means of furnaces, which produce sufficient draught to remove the necessary amount of air, and it has been frequently urged that a similar method might be used in the ventilation of sewers.

It was thought that an efficient ventilation of sewers could be effected by means of high chimneys, specially erected for the purpose or already existing in certain manufacturing establishments; the draught being produced by furnaces through which the sewer gases should pass and be consumed. This question has received great attention in England.

Mr. W. Haywood testified as follows as to the practicability of ventilating sewers by means of furnaces, before the Select Committee on the State of the River Thames: — †

"My impression is, that there will be exceeding difficulty in doing it at all; but, if it can be done, it will only be at an enormous annual expense. The difficulties to be overcome are

* Soyka, Munich Experiments, 1882.

† Report of Select Committee on the State of the River Thames, 1858.

gigantic. . . . The difference between a mine and a sewer is an essential difference; a mine . . . has but one inlet and one outlet for the purposes of ventilation; a sewer has thousands and tens of thousands. . . . All these openings are continually varying in their condition, and you must bear in mind that, supposing . . . the whole district had been so arranged as to have a sufficient exhaustive power, the mere opening of a water-closet, or the enlarging or putting in of a new drain into a sewer, or the making a hole a foot square, . . . or a sewer man lifting a side-entrance covering, would very much destroy the power of the furnaces; and, unless you had a gigantic power sufficient to guard against all these casualties, the system could only be a failure."

Sir J. W. Bazalgette, testifying before the same committee, said: —

"It is impossible so to arrange the sewers themselves as channels in mines are arranged with a view to ventilation, it being impossible so to trap the inlets to the sewers as to admit of a flow of sewage into them, and at the same time to prevent the passage of air from the nearest inlets to the furnaces. A furnace ventilating any large district would require to produce a very large volume of air, and to keep up a velocity sufficient to ventilate all the branch sewers, and the drag would consequently be so great through the main that it would force open any house-drain traps or water traps we could form, before it would influence the remote branches; but, putting those difficulties out of the question, — which appeared to us insuperable, — we found that the consumption of coal to extract the required quantity of air — supposing that the sewers could be laid out like the channels of mines — would be something enormous."

At the time of the sessions of this committee, the furnace of the clock-tower of the Houses of Parliament, which formed a part of the system for ventilating those buildings, had been connected with the sewers in the vicinity, and experiments were made to ascertain its efficiency in ventilating them.

These experiments showed that its influence was inappreciable except in its immediate vicinity, and the committee, in their report to the House of Commons, said: —

"This furnace system, therefore, even with the improvements introduced by Mr. Gurney, though possibly efficacious for a particular and limited area, could not be relied upon for the general ventilation and purification of the sewers of the metropolis at large."

Aside from questions of efficiency, the ventilation of sewers by means of furnaces is not void of danger. During the above-mentioned experiments, a portion of the sewers was found to contain quantities of coal gas, which had entered them from some leakage of the street gas pipes. An examination showed that these sewers had been isolated from the furnace by a flap valve which had not been raised. Upon raising it, an explosion took place at the furnace which caused considerable alarm. Another instance of an explosion is recorded, which occurred at a soap factory in London, whose furnace had been connected with the sewers for ventilation. This explosion was of sufficient force to destroy the establishment.

Other means for ventilating sewers by the production of an artificial draught have been tried, but have not proved successful. Drs. Parkes and Sanderson reported in 1871, concerning the efficiency of Archimedean screw ventilators at Liverpool.* After showing by experiment that the Archimedean screw ventilators really do the work which they profess to do, *i. e.*, that they actually remove a large quantity of air from the sewers, they conclude that, notwithstanding their mechanical efficiency, they exercise no practical influence in preventing the escape of sewer air into the streets and houses, for the reason that their size is out of proportion to the work they are supposed to perform. The diameter of the ventilators being under eight inches and that of the sewers being equal to that of a circle three feet in diameter, the sectional area of the sewer is about twenty times as great as that of the ventilators. Under such conditions, the movement, in the sewer, of air towards the ventilator, in either direction, "would be so small that, excepting in the immediate neighborhood of the outlet, it could not be measured by the most delicate instrument."

* Report on the Sanitary Condition of Liverpool, 1871.

The conditions which render ventilation by means of furnaces impracticable, namely, the great volume of air to be removed and the existence of innumerable inlets, act in a similar manner when other sources of motive-power are adopted for creating a draught, and, in the instance of Archimedean screw ventilators, necessitate that these screws should be very numerous as well as that they should be properly proportioned to the work to be done. Even with the most favorable arrangement, there is a liability that neutral points may exist midway between certain groups of ventilators acting in opposite directions.

Sir J. W. Bazalgette, reporting to the Metropolitan Board of Works in 1866, said:—*

"I entered carefully into the comparative advantages of ventilating fans and furnaces and into the expenditure of fuel requisite for the extraction of a given quantity of air under various conditions." After stating the reasons why such processes could not be successful in ventilating sewers, except at an enormous cost, he remarks, as to their relative efficiency, that "Steam jets, fans, and other mechanical contrivances worked by steam power do not affect the ventilation as satisfactorily as furnaces with the same expenditure."

Numerous other expedients for ventilating sewers have been tried at various places with different degrees of success depending upon local circumstances. Of these may be mentioned: (1) ventilation by means of perforated covers of man-holes and ventilators in the centre of the street; (2) by means of pipes to convey the sewer air to the street lamps, where the gases may be consumed; (3) by means of pipes leading to special flues constructed in houses, within the body of the walls, or near the chimney, or upon the outside of the house and running up above all windows; (4) by means of the house drains, which are then left untrapped and extended above the roof; (5) by deodorizing the exhalations with charcoal and various chemical reagents; and (6) by breaking the grade of sewers into steps upon steep inclines, thereby modifying the tendency of the gases to flow towards the extremities of the sewer.

* Report of the Metropolitan Board of Works for 1865-6, p. 83.

Of the first of these methods, it may be said, that it is the most usual method adopted in this country. When the manholes and ventilating shafts are sufficiently numerous, and the holes in the covers are so large that they do not become stopped with street detritus, this method has given fair results, provided the sewers are kept reasonably clean. It is often inoperative in winter when the snow in the streets has a considerable depth. This is certainly a serious defect, and should be guarded against by other provisions, as there is a greater liability for sewer gases to enter dwellings in winter, since the high temperature then maintained in houses is equivalent to a certain reduction of pressure on the house side of traps, and, to that extent, favors the breakage of their seal.

As the inlets to the catch-basins are likely to be kept free from snow, such of them as can be left untrapped without causing offence may be left in that condition to serve for ventilation when the openings in the centre of the street are covered with snow. John Simon, medical officer to the Privy Council and Local Government Board, wrote concerning the ordinary conditions of self-cleansing sewers provided with free communication with the air: * "A sewer in which these conditions are fulfilled will scarcely, if at all, under ordinary circumstances, cause appreciable odor at open (untrapped) gullies in the street; the air in it, if at times compressed, will not easily exert at the duly guarded inlets of house drains any such pressure as can make way for it into houses, and, in cases where accidental defects of house drains unfortunately permit sewer air to enter houses, the sewer air will be at its lowest degree of dangerousness. It is a great security for such perfect ventilation of sewers as is essential to the safety of houses, that, in addition to whatever special ventilating shafts are provided, street gullies should, as far as practicable, be left untrapped, and complaint of nuisance from any such gullies should not necessarily be taken as reason for trapping them." Such nuisance may be due to a foul state of the sewer, and its cause may be removed by proper cleansing. This method also has the advantage of being comparatively cheap and simple.

* Second Report, New Series, M. O. P. C., Introduction.

The method of ventilation by the use of street lamps has not proved a success.

The methods of ventilation by special flues, chimneys, external pipes, in and upon houses, and by the house drains, although said to be used with success in some places where a rigid inspection can be enforced, cannot be recommended for use in this country. The danger of leakage of sewer gas into houses from imperfect work, from the cracking and opening of joints caused by the settlement of buildings, from damage to the pipes and flues during repairs, etc., is too great to warrant the employment of these methods.

The experience of several of the large cities of Europe in the matter of sewer ventilation has been very extensive. The case of London may be taken as an example representing, in the main, the general results obtained. In 1876, the Metropolitan Board of Works, of London, published a report reviewing the experience and conclusions of that Board, concerning this subject, during twenty years.*

Amongst other things, the Board, in 1868, appointed a special committee to consider the question of the ventilation of sewers, with a view specially as to the desirability of offering a premium for the best practicable plan for preventing the escape of injurious gases from sewers, and, at the same time, of preserving the safety of those who work in them.

After four years of experiment and deliberation, this committee reported "that it was undesirable to offer a premium, as it appeared from their investigations that no one plan of ventilation, however well adapted to succeed locally, would be applicable to the whole of the metropolis." The Board adopted and confirmed this decision of the committee.

The result and conclusions of the Metropolitan Board of Works concerning the ventilation of sewers are given in the report above mentioned, in a classified form as follows: —

* Annual Report of the Metropolitan Board of Works for 1876, App. 8.

"*A. General Conclusions.*"

"1. That some provision for the ventilation of sewers is absolutely necessary, both for the safety of the men engaged upon cleansing, repairing, and other necessary works in the sewers, and for the stability of the sewers themselves in the event of an explosion."

"2. That the method of ventilation adopted in mines where there are only two openings to be dealt with (an inlet for the air at one end, and an outlet for it at the other) is inapplicable to sewers."

"3. That the most efficacious and widely applicable mode of preventing the escape of offensive effluvia from the sewers is to provide them with such a copious supply of water that the decomposing matter within them shall be diluted and removed before any noxious gases have been generated."

"4. That ventilation by air-shafts from the sewers into the centres of the streets is a great improvement upon the old system of ventilation through the gully gratings at the sides of the streets."

"5. That it is inexpedient to incur a large expenditure for the purpose of making experiments to determine the value of the plan of ventilating sewers by means of furnaces."

"6. That it is unadvisable to offer a premium by public advertisement for the best practicable plan for the ventilation of sewers, inasmuch as no one plan, however well adapted to succeed locally, would be applicable to the whole of the metropolis.

"7. That a reward of 40 shillings [$10] be paid to any person giving such information to the Board as shall insure the conviction of any person or persons turning steam, or fumes and drainings from chemical or other factories, or any other deleterious substances contrary to law, into the sewers belonging to the Board."

"*B. Methods of Ventilation that have been tried in different localities with a variable amount of success.*"

"1. That the method of ventilating sewers by means of shafts or tubes placed at each end of the street and carried above the summits of the houses has been favorably reported on by the engineer."

"2. That the connection of sewers with rain-water or other pipes carried to the tops of the houses has been adopted with some degree of success, but is not capable of general adoption in consequence of the liability of the gas to descend into the chimneys and windows of such houses, and also in consequence of the great objection raised by most owners of property to such an arrangement."

"3. That the plan of ventilating sewers by means of air-flues connected with the furnaces and shafts of factories, and other buildings, considerably improves the ventilation of the sewers, in the immediate vicinity, but, in consequence of the great number of openings in the sewers of the metropolis, it is questionable whether a large portion of the noxious gases evolved is actually consumed by this method."

"4. That charcoal ventilating grates may be advantageously employed for deodorizing the gas issuing from such air-shafts as are sources of annoyance and complaint; but, inasmuch as their use tends to retard the effective ventilation of sewers, such ventilating grates should be cautiously and not generally applied."

"5. That the plan of deodorizing effluvia from sewers by means of sulphurous acid has been attended with partial success, but the benefit of the acid was in some cases neutralized by contact with steam and naphtha vapors."

"6. That the nuisance caused by the escape of the noxious effluvia from the ventilating shafts of sewers may in some cases be remedied by subjecting such effluvia to the action of chlorine gas, by means of an apparatus for that purpose being fixed in the shafts."

"7. That in a case where a sewer had been ventilated through a chimney shaft, and the furnaces connected with the shaft had

been discontinued, it was not advisable to provide gas jets in lieu of them."

"8. That the nuisance arising from ventilating gratings can be temporarily remedied by covering such gratings with iron plates, to be removed only when the workmen are engaged in the sewer."

"9. That the various expedients of intercepting valves, flexible screens, and the like have in some places been employed with advantage to regulate the ventilation of sewers."

"*C. Various Schemes that have from time to time been submitted to the Board with reference to the Ventilation of Sewers.*"

"1. That the attempt to carry out the ventilation of sewers by means of a water fan would prove a failure."

"2. That the division of sewers into sections by means of valves, and the connection of each section with a furnace, are not generally applicable."

"3. That the plan of ventilating sewers by means of a pipe attached to the street gas lamps, and also the plan of using sulphur lamps to arrest the putrefaction of matter in sewers, are both inapplicable."

"4. That the construction of two fans at Crossness for the purpose of drawing the foul air from the sewers is impracticable."

"5. That the plan of ventilation by the connection of house drains with pipes constructed in the party walls and carried into the chimneys is not generally applicable."

"6. That the plan of purifying sewers by drawing smoke into them is not of a practical character."

"7. That the plan of cleansing sewers by means of travelling scoops is inapplicable.

"8. That the results obtained by the patent ventilator tried by the Board did not present any marked difference from those of the ordinary ventilator."

"9. That the prevention of the escape of foul gas from sewers by pouring some fluid preparation into the drains is impracticable."

THE SEPARATE SYSTEM.

The principle of conveying the storm water and the sewage proper by separate and distinct channels has been urged for more than forty years.

As has been stated already, the earlier types of sewers were built for the conveyance of surface water and the drainage of the land. The admission of fæcal matter into them was an after-consideration, and followed the introduction of water-closets and public water-supplies.

With a largely increased volume of fluids to be removed, it was natural that existing channels should be utilized as far as practicable, and the precedent of using a single system of sewers for the conveyance of all matters became established.

The frequent stoppages and accumulations of filth in sewers of the primitive types led to prolonged discussions of the fundamental principles of water carriage. The conveyance of sewage in a distinct system of sewers is believed to have been first suggested as early as 1842 by Mr. Edwin Chadwick.

In 1846–7, Messrs. Roe and Phillips urged the adoption of pipe sewers for the sewerage of towns, instead of the enormous sizes then in vogue, and in 1847 the latter matured a project for the exclusion of storm water from the sewage. In 1849, Mr. Phillips proposed the separate system for adoption in the drainage of London, but the authorities were not then willing to introduce so radical a change. During the two following years the separate system was adopted in Alnwick and Tottenham, which are believed to be the earliest examples of sewerage works in which the surface water and subsoil drainage were separated from the sewage.

In 1852, the General Board of Health published a blue book officially advising the use of small pipes for sewers. This was followed by a long and bitter controversy upon the subject of brick *vs.* pipe sewers, in professional circles, in which the most extreme ground was taken on both sides. The small-pipe system was constructed in quite a number of towns in England

with various degrees of success, and several towns adopted the principle of excluding the surface water from the sewers.

The separate system has been in use in this country for quite a number of years. It has been adopted by some fifteen or twenty towns in the United States, among which may be mentioned the city of Memphis, Tenn., sewered by Col. Geo. E. Waring, Jr., C. E., in 1879; Pullman, Ill., sewered by Mr. Benezette Williams, C. E., in 1880; and Nahant, Mass., sewered by Mr. Ernest W. Bowditch, C. E., in 1883. It is also being tried experimentally in a limited section of Paris.

The separate system contemplates the removal of house sewage and liquid manufacturing wastes through an independent system of pipes whose dimensions are proportioned to the volume of sewage passing through them. It is essentially a system for the removal of *filth* by water carriage, the water being limited to the smallest necessary quantity.

The amount of sewage conveyed by such a system of sewers is consequently very uniform. With it, when properly constructed, there are no accumulations of deposits in the sewers, generating noxious gases and only to be removed by the powerful action of a severe storm; but the sewers being daily filled to their maximum working capacity at the hour of maximum flow, the main lines are daily swept clear of solids, and the sewage is rapidly and completely carried to the outfall before any putrefactive change has taken place in it.

In the primary lateral sewers, the amount of sewage is usually insufficient to keep the sewers clean, and here some artificial method of flushing becomes necessary. This may be effected by automatic flush tanks connected with the public water supply. They are gradually filled by a small stream of water, say of five gallons per hour. When a tank is full the continuous flow of the entering water produces a small overflow which sets a siphon in operation, and the entire contents of the tank are discharged into the sewer with great rapidity, producing a powerful flush. Other flushing arrangements operated by hand may be used if preferred.

The removal of the storm water is treated under this system as a separate and independent question. It is permitted to

flow over the surface of the ground as far as it is practicable to do so. When its volume becomes so augmented as to cause trouble, it is conveyed underground by channels at a slight depth, and is led to the nearest water-course by the most direct and cheapest route. The storm water may be discharged into the water-courses at several places, according to the topography. The sewage, however, is usually conveyed to a single outfall, where it may be treated chemically, or may be used in irrigation.

The experience of English engineers has led them to consider it impracticable to exclude the rain falling upon private property from the foul water sewers, because this would require two sets of house drains in many cases; one for sewage, connecting with the sewer, the other for the surface drainage of the yard and roof, and leading to other channels. They consider that it would cause many complications, and that it would be an unwarrantable exercise of authority to require the construction of two sets of house drains. They also consider that the admission of a limited amount of rain-water to the foul water sewers is an important factor in maintaining their cleanliness, and the prevailing practice with them, when separation is attempted, is to exclude only the rain-water in the streets and public squares, and to admit the rain-water from yards and the rear roofs of houses.

The practice in this country has tended towards a more complete separation of the sewage and the rainfall. This is due in part to the extreme views of some of the advocates of the separate system, and in part, no doubt, to the difference between the climates of the two countries; heavy rainfalls being more common here than in England.

The separation of the rainfall from the sewage becomes important when the sewage must finally be pumped, and when it must be treated chemically or used in irrigation. On the other hand, the separation of the sewage from the rainfall beomes important when the rainfall passes into streams that must afterwards serve as the sources of public water supplies. These conditions, demanding separation, are frequently found associated together.

The question as to the necessity for separation, and of the proper method of removing storm water, is further complicated by the fact that the first wash of water after flowing over the

streets of cities, and being contaminated with the droppings of animals and other filth, becomes a variety of sewage possessing nearly, if not quite all the constituents of ordinary sewage except the peculiar germs of disease associated with human excrement, and except certain chemical products derived from manufacturing waste. By thorough and systematic scavenging the streets may be kept in such a condition that the storm water may cause little harm if permitted to pass directly into the streams, but this ideal of sanitary work is seldom attained, and the first washings of the streets during storms are usually extremely foul.

Another phase of the surface drainage of towns presents itself in the larger Northern cities in winter, when a thaw occurs after a long period of snow. The mingled accretions of snow, ice, and filth, that have been weeks in accumulating, are then liberated in liquid form in great volumes, and require prompt removal. At such times the capacity of sewers receiving surface water is severely taxed, ordinary surface channels are so obstructed as to require constant attention, and floodings frequently occur in the lower districts; travel being greatly impeded, and property in basements and cellars being often damaged.

The great cost of sewers large enough to convey all the waters of heavy storms has already been referred to, it being prohibitory in most instances. Consequently the question as to the best method of removing storm water is reduced to a consideration of the objections, from the sanitary or from the financial point of view, to the admission of a portion of the surface drainage to the sewers conveying sewage.

The advocates of the separate system claim, among other things, that some of the earthy matters carried into the sewers by turbid storm water, particularly building lime, act as precipitants, and cause the deposit of organic matter within the sewers, intermixed with deposits of road detritus, leaves and twigs, brought into the sewers by storm water. These deposits, when not removed by the ordinary flow of sewage or by flushings, must remain until the next heavy storm, and meanwhile become the source of noxious exhalations.

The essential difference between the two systems, as regards cleanliness and freedom from deposits, arises from the fact that in the separate system the substances to be removed are derived from domestic and manufacturing wastes, while in the combined system there are, in addition, the substances brought into the sewer by the storm water. Thus, while the scouring power of the sewage in the combined sewers is, at the best, no greater than in the separate sewers, and may in certain cases be less, the amount of deposits in them may be greater, and their nature may be such as to render them more difficult of removal. Another result derived from the use of small pipes, as in the separate system, is that a given volume of water, such as the contents of a flush tank, will produce a greater scour and will more completely wash the interior of the sewer; or, to state it differently, a less amount of water will be needed to remove a given obstruction.

Great stress is laid by the advocates of the separate system upon the more perfect ventilation of the sewers when their size is small as compared with the ordinary volume of sewage flowing through them.

It is also claimed that organic matter adheres to the upper portions of the interior of sewers of the combined system when they are conveying storm water, and remains after the storm has ceased, forming a slimy coating; that this soon becomes putrid and promotes the developement of swarms of microscopic organisms. On the contrary, it is claimed that the sewers of the separate system being filled every day to their maximum working capacity, afford less opportunity for the growth of noxious germs.

A comparison between the separate and combined systems from the financial point of view cannot be made explicitly, as such a comparison must be based upon local circumstances to a certain extent. This much, however, may be said concerning it.

The cost of a sewer depends upon a number of elements, some of which are independent of the size contemplated; thus the cost of sheeting and bracing the trench, of pumping water from wet soils, and to a very large extent the cost of excavation, back filling, and paving will not be essentially reduced by dimin-

ishing the size of the sewer. The difference in cost occasioned by the use of a smaller sewer is, however, generally in favor of the smaller sewer.

A comparison between the cost of a system of combined sewers, and of a system of sewers from which surface and subsoil waters are excluded, will generally show that the latter can be built more cheaply. It should be remembered, however, that the greater cost of the combined system is offset by the provisions for the admission and removal of storm water. If the necessities of the locality require that the surface and subsoil waters shall be removed by underground conduits, their cost should be added to the cost of the house-drainage sewers in order to make the comparison valid. Should these underground conduits be equal in extent to the system of house-drainage sewers, the cost of the entire combination will usually exceed the cost of a "combined system." In most instances the conduits for surface and subsoil water need not be coextensive with the house-drainage sewers, nor do they need to be placed at so great a depth. Consequently a great many instances exist where a separate system would remain the cheapest after the addition of the cost of the necessary channels for removing the surface and subsoil water.

Mr. Eliot C. Clarke, C. E., in an elaborate and exhaustive discussion of this question, arrived at the conclusion,* "That the saving in first cost of sewers, where all of the rain flows off over the ground, will be about three fifths, depending on the character of the soil; that the final economy will depend on circumstances; . . . that surface drainage for rain is attended by a varying amount of inconvenience and damage, which increases with the growth of a town."

The separate system has been extensively discussed both in professional and popular literature. While it is generally admitted that this system possesses great merit and is particularly valuable in the development of small towns, it is not admitted that the combined system deserves all the censure that has been heaped upon it, nor that the separate system is

* Mass. Board of Health, L. and C., Supplement on Public Health, 1880.

intrinsically the best in all cases, as has been claimed. Each system has its defects as well as merits, and the choice between them will depend upon local conditions. The two systems may be used, in some cases, in different parts of the same city, with better results than would be obtained from the exclusive use of either.

THE DISPOSAL OF SEWAGE.

HISTORICAL.

The subject of the utilization and disposal of sewage has long occupied the attention of scientists and legislators, and is continually increasing in importance in every community with the increase in the density of population. It has already become a question of great moment in this country, and it has for many years been one of the most pressing questions connected with the public health of Europe. It is intimately associated with the pollution and purification of rivers, with the pollution of the soil and atmosphere of towns, with the purity of supplies of potable water, with the salubrity of seaside resorts, with the maintenance and development of fish supplies, and with kindred subjects.

The small area, great density of population, and multiplicity of manufactures in England have combined to produce extensive pollutions of rivers and sources of water supply in that country. Public opinion, consequently, early demanded a solution of these difficulties, and the questions involved have been examined and reported upon at great length by various government commissions and committees. Their reports, together with others from government officials, from commissions appointed by various English towns, as well as essays published in the proceedings of professional and scientific societies, and in current scientific journals, reports of engineers, and miscellaneous writings, form an exhaustive literature upon the subject that is unequalled in any other language, and has become the

standard authority, except in matters concerning which the climate of England may have produced exceptional results.

The limits of this report do not permit even an enumeration of the titles of this mass of literature, much less an analysis of their contents; it may be well, however, to mention briefly a few of the more important British government reports, as they are frequently referred to in writings on this subject.

Passing without further mention the report of the Select Committee on Metropolitan Sewage Manure to the House of Commons in 1846, the reports of the Metropolitan Sanitary Commission in 1847–48, and of the General Board of Health in 1852 and several subsequent years, should first be noticed.

At the time that these reports were written, the disposal of sewage by other methods than by allowing it to flow into watercourses and into the sea had only been attempted in a few places and on quite a limited scale. It was generally considered that efforts for the disposal of sewage should be directed towards the development of its use as a manure, and the reports of the General Board of Health in 1852 deal largely with its use in this way; either by the method of irrigation, as has been practised at Edinburgh and Milan for many years, or by the use of fixed pipes and the hose and jet, by which the sewage was conveyed under hydraulic pressure to the places where it was to be used, and was sprinkled over the ground and vegetation. This latter method of application, although giving good results in certain respects, has never been extensively adopted on account of the labor involved, and more especially for the reason that it is considered imprudent, for sanitary reasons, to permit sewage to come in contact with the leaves and stalks of vegetation.

Meanwhile other methods of disposing of sewage had been developed and applied experimentally and had promised excellent results.

In 1857, Henry Austin, C. E., Chief Superintending Inspector of the General Board of Health, made a report to the President of the Board, reviewing the aspect of the sewage question and describing the means in use for deodorizing and utilizing sewage and its manufacture into solid manure. This

report described the chemical and mechanical processes then in use for separating the solid matter of sewage, the utilization of the liquid portions by irrigation and by underground pipes, and gave some agricultural results from the use of sewage manure.

The conclusions arrived at in that report may be thus briefly summarized: That the evils caused by the direct discharge of sewage imperatively called for remedy; that the practical experience obtained at Edinburgh and Milan had shown the great value of sewer water on grass lands, although applied in a state of great dilution, while valuable experiments had shown the power of soils to remove from solution and retain for vegetation the fertilizing elements; that complaints of nuisance had been made concerning the irrigation method, but that the sources of nuisance and danger are preventible and should not be tolerated; that it appeared that the solid matter should be separated from the liquid sewage at the outfall, in every case, from which a cheap portable manure should be manufactured to be used in the immediate neighborhood; that it seemed probable that such an operation would, in most places, pay its own expenses, but that the public health rather than profit should be invariably considered; that the liquid portion of the sewage, thus cleared of its solid matter, but still retaining its chief value as manure, might then be applied with benefit to the neighboring lands in any quantity; that such lands, if not naturally porous, should be artificially drained, otherwise, the liquid, if allowed to stagnate, might engender disease; that the results obtained from the hose and jet system appear to justify the outlay necessary for such works, but that better results may be obtained by irrigation; that in places where no opportunity exists for irrigation, the liquid sewage, after the separation of the solid matter, should be treated with deodorizing and precipitating agents before being discharged into rivers and streams, and "that it is an object of immense public concern that the poisonous accumulations of our towns, now fast becoming the sources of pollution of our rivers and streams, should without delay be rendered powerless for further mischief, and applied, as nature's law demands, for reproductive

uses. That by this means the greatest sanitary problem will be solved, and the greatest advancement of agricultural prosperity secured."

Public opinion in England at this period was urgent that some measures should be taken to remove these sanitary evils, and in the same year, 1857, a Royal Sewage Commission, known sometimes as "The Sewage of Towns Commission," was appointed "to inquire into the best mode of distributing the sewage of towns, and applying it to beneficial and profitable uses."

The deliberations of this commission extended over a period of eight years, and embraced a variety of inspections, chemical analyses, and experiments, of a careful and exhaustive character. The results obtained may be considered as representing the actual state of the sewage question at that time. The commission made a preliminary report in 1858, a second report in 1861, and a third and final report in 1865. This latter is very brief, but is accompanied by voluminous reports of experiments, and appendices. The report is substantially as follows: —

. . . "Since the date of our last report (August, 1861) we have . . . continued at Rugby the experiments which were undertaken in 1861, on the application of sewage to lands. . ."

"Your Lordships will observe that these experiments have not been confined to the application of sewage in different quantities to land, but have extended to the consumption, by cattle, of the produce so obtained, and to the production of meat and milk, and have been accompanied by a careful record of the quantities and market value of the products, and by numerous analyses of the sewage before and after irrigation as also of the grass and of the milk."

"It appears to us that these experiments have solved many of the difficulties which have hitherto attached to the question of the agricultural application of sewage, and that they leave no reasonable doubt of the practicability and advantage of so employing the sewage of towns."

"We have also continued to give our best attention to all kindred experiments and inquiries, which have been going on elsewhere."

"As the results of our labors, extending over eight years, we have confidence in submitting to your Lordships the following conclusions: —

"1. The right way to dispose of town sewage is to apply it continuously to land, and it is only by such application that the pollution of rivers can be avoided."

"2. The financial results of a continuous application of sewage to land differ under different local circumstances: first, because in some places irrigation can be effected by gravity, while in other places more or less pumping must be employed; secondly, because heavy soils (which in given localities may alone be available for the purpose) are less fit than light soils for continuous irrigation by sewage."

"3. Where local circumstances are favorable, and undue expenditure is avoided, towns may derive profit, more or less considerable, from applying their sewage in agriculture. Under opposite circumstances, there may not be a balance of profit; but even in such cases a rate in aid, required to cover any loss, needs not be of large amount."

"Finally, on the basis of the above conclusions, we further beg leave to express to your Lordships that, in our judgment, the following two principles are established for legislative application: —

"First, that wherever rivers are polluted by a discharge of town sewage into them, the towns may reasonably be required to desist from causing that public nuisance.

"Second, that where town populations are injured or endangered in health by a retention of cesspool matter among them, the towns may reasonably be required to provide a system of sewers for its removal.

"And should the law, as it stands, be found insufficient to enable towns to take land for sewage application, it would, in our opinion, be expedient that the legislature should give them powers for that purpose."

In February, 1862, about five years after the appointment of the Royal Sewage Commission, and while its labors were still in progress, the House of Commons ordered that a select committee be appointed "to inquire into the best means of utilizing the

sewage of the cities and towns of England, with a view to the reduction of local taxation, and the benefit of agriculture."

This committee, which is generally known as the Select Committee on Sewage of Towns, made two reports to the House, in April and July of the same year.

Their first report was merely a statement of progress and an expression of approval of the work of the Royal Sewage Commission. Their second report consisted of a statement of general principles in very guarded language. It was followed by an elaborate analysis of the evidence taken by the committee, in which the details of the subject were more fully given. The work of this committee was to a certain extent a repetition of the work of the Royal Sewage Commission, and its existence is an indication of the importance attached to the sewage question in England at that period.

This is still further shown by the appointment, by royal authority in May, 1865, of a commission to inquire into the best means of preventing the pollution of rivers; the date of this appointment being but three months subsequent to the termination of the work of the Royal Sewage Commission.

The Rivers' Pollution Commission of 1865 made three reports, the first in 1866, and the second and third in 1867. Their commission was revoked in February, 1868, and in April, 1868, a second Rivers' Pollution Commission was appointed, This second commission made six reports, the first in 1870, and the sixth in 1874.

The subjects embraced in the reports of the two Rivers' Pollution Commissions may be best stated in the language of their commissions. They were appointed "for the purpose of inquiring how far the present use of rivers or running waters in England for the purpose of carrying off the sewage of towns and populous places, and the refuse arising from industrial processes and manufactures, can be prevented without risk to the public health, or serious injury to such processes and manufactures, and how far such sewage and refuse can be utilized and got rid of otherwise than by discharge into rivers or running waters, or rendered harmless before reaching them; and also for the purpose of inquiring into the effect on the drainage of lands and

inhabited places, of obstructions to the natural flow of rivers or streams, caused by mills, weirs, locks, or other navigation works, and into the best means of remedying any evils thence arising."

The reports of the two Rivers' Pollution Commissions embrace the basins of the rivers Thames, Lee, Aire, Calder, Mersey, and Ribble, as well as the rivers of Scotland. They also made separate reports upon the A. B. C. process of purifying sewage; upon the pollution arising from the woollen manufactures and processes connected therewith; upon the pollution arising from mining operations and metal manufactures, and upon the domestic water supply of Great Britain. These reports, with the accompanying minutes of evidence and indices, were published by Parliament in fifteen folio volumes.

The various administrative functions necessary for a proper execution of the sanitary laws of Great Britain, which at various times have been vested in the General Board of Health, in the Secretary of State, in the Privy Council, in the Poor Law Board, and in local boards of health, were transferred in 1871 to a new executive authority, called the Local Government Board, whose duties embrace some of the functions of a national board of health.

It is required, among other things, that all projects for local drainage, sewerage and disposal of sewage shall be submitted to this Board, whose approval is necessary before such projects can be legally executed, and whose sanction must be had for any special tax or loan required for their construction.

In 1875, the attention of the Local Government Board having been called to the great difficulties experienced by sanitary authorities in regard to the disposal of sewage, and their advice having been repeatedly asked concerning such matters, the President of the Board deemed it expedient to appoint a committee of the Board, to make a special inquiry into the practical efficiency of the chief systems of sewage disposal then in operation, and for which loans had been sanctioned by the Board. This committee reported in 1876. Their report,* which was presented to Parliament by command, may be considered as the

* Sewage Disposal. Report of a Committee [etc.], 1876.

official statement of British experience in the disposal of sewage up to that date. The conclusions of this committee, so far as they relate to the disposal of water-carried sewage, are as follows:—

"1. That the scavenging, sewering, and cleansing of towns are necessary for comfort and health . . . ."

"2. That the retention . . . of refuse and excreta . . . in cesspools . . . or other places in the midst of towns must be utterly condemned; and that none of the (so-called) dry-earth or pail systems or improved privies can be approved other than as palliatives for cesspit-middens. . . . "

"3. That the sewering of towns and the draining of houses must be considered a prime necessity. . . . "

"4. That most rivers and streams are polluted by a discharge into them of crude sewage, which practice is highly objectionable."

"5. That, as far as we have been able to ascertain, none of the existing modes of treating town sewage by deposition and by chemicals in tanks appear to effect much change beyond the separation of the solids, and the clarification of the liquid. That the treatment of sewage in this manner, however, effects a considerable improvement, and, when carried to its greatest perfection, may in some cases be accepted."

"6. That, so far as our examinations extend, none of the manufactured manures made by manipulating town's refuse, with or without chemicals, pay the contingent costs of such modes of treatment; neither has any mode of dealing separately with excreta, so as to defray the cost of collection and preparation by a sale of the manure, been brought under our notice."

"7. That town sewage can best and most cheaply be disposed of and purified by the process of land irrigation for agricultural purposes, where local conditions are favorable to its application, but that the chemical value of sewage is greatly reduced to the farmer by the fact that it must be disposed of day by day throughout the entire year, and that its volume is generally greatest when it is of the least service to the land."

"8. That land irrigation is not practicable in all cases; and, therefore, other modes of dealing with sewage must be allowed."

"9. That towns, situate on the seacoast, or on tidal estuaries, may be allowed to turn sewage into the sea or estuary, below the line of low-water, provided no nuisance is caused; and, that such mode of getting rid of sewage may be allowed and justified on the score of economy."

Although the method of disposal by application to land was preferred in the government reports, the advocates of chemical methods were not idle during this period. Public opinion having been thoroughly awakened to the necessity of ameliorating the existing state of affairs, it was not difficult to persuade many that a valuable source of revenue could be found in the sewage that was so freely discharged into the streams, by extracting from it its fertilizing constituents, and making from them a merchantable manure, and that vast fortunes awaited those who should successfully solve this problem.

Numerous schemes were consequently proposed for the utilization of town sewage, various stock companies were formed, and capital was largely invested. This action was further stimulated by the fact that many inland towns, whose sewage was being discharged into rivers, were obliged to devise means for its disposal, either from the compulsion of the authorities, or from their own perception of the necessity for so doing.

With an urgent demand on one side and credulous capitalists on the other, projects for utilizing sewage were brought forward almost without number. The most extravagant claims were made of the capability of these projects to effect wonders in making sewage a source of wealth. After a short time they were abandoned, one by one, as unremunerative, and the public became convinced that no process for the chemical treatment of sewage could be made to pay; that irrigation with sewage may prove a financial success only when all the conditions are favorable to such a result; and that the disposal and utilization of sewage should be undertaken for the improvement of the public health and not from a view to pecuniary profit.

The necessity for resorting to chemical methods has not been as great on the Continent as in England, as land could be more easily obtained, and the irrigation method of disposal has been adopted in nearly every instance on the Continent.

In this country very little progress has been made towards abating the sewage nuisance. With scarcely an exception, the prevailing practice has been to allow the crude sewage to flow into the nearest river or large body of water. The deplorable results produced in many places by this method of disposal are too well known to require comment. In a very few instances some attempt has been made to utilize sewage by irrigation, the most notable being Pullman, Ill.

THE DISPOSAL OF SEWAGE BY IRRIGATION.

The method by which earth acts as a purifier of foul liquids was first examined scientifically by Dr. Frankland, of England. The results of his examinations are given by the Rivers' Pollution Commission in their first report, published in 1870. The subject was also very carefully examined by the French engineers in charge of the sewage works of Paris.

The general theory of the purifying action of the soil may be stated as follows, abridged from a report by MM. Schloesing and A. Durand-Claye.*

When an impure liquid, such as sewage, flows upon a permeable soil, the larger insoluble particles are arrested by the surface, as by a filter. Such particles as are sufficiently minute to pass into the earth are caught before they have proceeded far downwards. This is the first action, that of a mechanical filter.

The water, freed of its insoluble matters, descends still lower, and is absorbed by the soil; each particle of earth being surrounded with an extremely thin coating of the liquid. Thus subdivided, the water presents an enormous surface to the air contained within the soil. The second action of the soil now comes into operation. An action similar to slow combustion takes place in the interior of the soil. By this action, not only are all organic impurities reduced to carbonic acid, water, and nitrogen, as in active combustion, but the organic nitrogen itself, which is much more difficult to oxidize than either car-

* Schloesing et A. Durand-Claye, Rapport au Congrès International d'Hygiène de Paris, 1878.

bon or hydrogen, is changed into inorganic compounds. The insoluble matters, retained at the surface, are also affected by slow combustion, especially when they have been incorporated into the soil. They are reduced to an extremely fine dust, and mingle with the mineral elements of the earth.

Experiments made by MM. Schloesing and Müntz, of Paris, have thrown considerable light upon this remarkable property of the soil in purifying sewage.

The moist materials, usually found to a greater or less degree in all soils, do not seem to be indispensable to this process. Sand that has been heated to redness, and consequently deprived of all traces of organic matters, was found to effect the complete purification of sewage and the complete nitrification of its organic nitrogen, after the experiments had been conducted a sufficient length of time; one condition being that the amount of sewage poured upon the sand daily should be such as to require at least eight days to pass through the sand used in the experiment, which should possess a thickness of some six or eight feet. The process of nitrification, however, is completely arrested when the vapor of chloroform is introduced into the sand. Moreover, M. Müntz has proved that this anæsthetic has the effect of paralyzing organisms which act as ferments. It therefore becomes extremely probable that this nitrification may be dependent upon the life of organisms capable of carrying the oxygen of the air to the most diverse organic matters; the *mycoderma aceti* and others, whose functions have been so well described by M. Pasteur, possess this power.

Sewage contains sufficient organic and mineral matters to nourish such organisms without the aid of the moist materials of the soil; therefore sand, as well as vegetable earth, can be used for purifying sewage. Purfication by sand does not occur when sewage is first applied. The germs of the nitrifying organisms being absent, it is first necessary that they should be introduced and developed in sufficient quantity in the sand. Ordinarily, purification does not begin until several weeks have elapsed. In vegetable earth it commences at once, as the organisms are already in the soil. With this exception, sand prop-

erly accessible to the air is as good as the richest earth, so far as purification is concerned.

This theory evidently does not exclude the possibility of nitrification by slow combustion, produced by oxygen solely through the action of physical and chemical forces, and without the intermediate agent of life. But the labors of M. Pasteur show that certain organisms produce nitrification far more energetically than do the chemical forces.

Soils containing various proportions of loam are suitable for the purification of sewage, while at the same time they utilize its elements. But the poorest soils, even pure sand, effect after a very short time quite as perfect a purification; the sewage itself supplying the organisms which produce nitrification. These are already present in loamy soils.

The action of plants is often spoken of as assisting the soil in the purification of sewage. In this there is doubtless a confusion of ideas. The bare soil, without vegetation, possesses great purifying powers. This is shown by the continued purification of sewage during winter, or in summer between two consecutive crops.

The conditions necessary for perfect purification are these. There must be a flow of sewage and a flow of air. The movement of the sewage takes place successively, in three different ways; its distribution over the surface of the ground, its passage through the soil, and its discharge after being purified. The movement of the air consists in exchanges between the earth and the atmosphere, resulting in the constant renewal of the oxygen in the soil as it is exhausted by the combustion of the impurities in the sewage. The purifying power of the soil is evidently dependent upon these various motions. The aeration and the circulation of the sewage act in bringing together the oxygen and the combustible matter in the desired proportions.

The purifying power of any soil, or, in other words, the amount of impurities which it can destroy in a given time, is peculiar to itself. Whatever it is found to be, so it must be used. The aeration cannot be completely controlled, but much can be done to promote it. It is increased by loosening the soil, and by drainage. It can be destroyed by an excess of

irrigation. When the soil has received the mechanical preparations needed to aid the circulation of the air, nothing more can be done to promote aeration, except by regulating the amount of sewage applied. The movements of the sewage, therefore, should always be under complete control.

Purification is a species of continuous slow combustion; the circulation of the air is a mechanical fact, also continuous. Perfection in the movements of the sewage would therefore consist in rendering them continuous in their turn. But this is impracticable. The application of sewage to the soil is necessarily intermittent, and its passage through the soil and subsequent discharge consequently become so. This intermittence, suitably regulated, does not destroy the continuity of the main action, but it is evident that the application of the sewage should be restricted within proper limits, as regards time and quantity, otherwise the purification would be rendered incomplete.

When water is applied to the surface of a porous soil, it penetrates it by displacing an equal volume of the water already in the soil, which passes away at the bottom by natural or artificial drainage. Sewage spread upon the land in intermittent irrigation acts in the same way. The liquid of one application displaces that of the preceding, and the interior of the purifying soil may be conceived as divided up into horizontal layers, each of which is occupied by the liquid of a single application. It is during the passage of the sewage through the soil in this manner that its purification takes place.

This purification is slow and continuous and requires a certain amount of time. The passage of the sewage through the soil likewise requires a certain amount of time, and if this latter is less than that required to purify it, the sewage will pass away without being perfectly purified. On the contrary, if the duration of its passage is equal to, or if it exceeds, the time required for purification, this latter will be complete and the impurities will be completely removed. Thus it is clearly seen that the amount and frequency of the irrigations must be so regulated that the sewage may remain in the soil long enough for perfect purification to take place.

It is impossible to make a general rule which shall govern the amount and frequency of irrigations. There is too much uncertainty in the data upon which such a rule would depend; such as the purifying capacity of the soil under consideration, its depth, and the quantity of water which it will retain by capillarity. In each particular case a simple calculation, based upon experiments upon the soil in question, will be necessary.

The gradual displacement of the liquids in the soil is interfered with when too much is applied at once. If the waterings are made by large quantities applied at long intervals, a portion of the sewage will descend at once to the bottom, and will escape without being purified. The more frequent the waterings, and, consequently, the smaller the amount applied at each, the more regular will be the descent of the water through the soil by displacement, and the more perfect will be the purification. Daily waterings sometimes interfere with cultivation, and consequently may be impracticable; but care should always be taken not to apply too much at once, and thereby compromise the purification. Whenever, in the interests of cultivation, the waterings are suspended or diminished, no attempt should be made to make up for lost time by giving the soil more than it is able to purify.

In the case of compact soils resting on an impervious substratum, under-draining is necessary. Without it the water would accumulate in the interstices of the ground, driving out the air, preventing aeration, the combustion of organic matters, and, consequently, purification. Putrefaction would then take possession of the soil. Under-drainage is sometimes needed in the case of porous soils resting upon an impervious substratum, when the surface of the latter has not sufficient inclination to allow the water to flow off with sufficient rapidity.

The Rivers' Pollution Commissioners write as follows concerning the purifying power of different soils: —*

"The cleansing power of a soil seems to be more closely connected with physical conditions, as regards porosity and fineness of division, than with its chemical composition. Thus, the

* First Report, Mersey and Ribble Basins, 1870.

Beddington and Barking soils, whilst similar in chemical composition, are most widely dissimilar in their action upon sewage. Again, sand and Hambrook soil act very similarly upon sewage, whilst they differ considerably in chemical composition, and lastly, the Hambrook and Dursley soils do not differ very widely in their chemical composition; nevertheless the latter has more than twice the purifying power of the former.

"These experiments upon the filtration of sewage through various materials leave no doubt that this liquid can be effectually purified by such processes, and that probably any variety of porous and finely divided soil may be employed for this purpose. Our experiments also appear to show that if the soil be not overdosed with sewage, it will retain its efficiency for a long, if not for an unlimited, period of time, and its pores will not become clogged up."

The subject of sewage irrigation has been here treated solely from the standpoint of *purification*, and it has been shown that this can be effected by applying the sewage to porous soils, and that in its passage through such soils, if properly regulated, all its impurities are destroyed. But these impurities constitute the fertilizing principles of sewage, which are lost through the oxidizing action of the soil. It is therefore necessary to consider the subject from the standpoint of *utilization*.

* The distinction between purification and utilization is fundamental, and cannot be too strongly insisted upon. As will be shown, it is impracticable to extract all the fertilizing constituents from sewage. Therefore, in applying them to agricultural uses it becomes necessary to apply the water also. That is, we must irrigate. To purify the sewage we may also irrigate. It therefore seems that the two questions, purification and utilization, are solved by the same process. Their solutions differ, however, in an essential point, inasmuch as utilization, to be complete, requires a much greater area.

For example: it has been estimated that the sewage of Paris is each year equal to 1,200,000 tons of farm manure; and that if applied to 40,000 hektares (100,000 acres) of land it would

* Schloesing et A. Durand-Claye, *loc. cit.*

form a much richer dressing than is generally used by the French farmers. When all fæcal matters are allowed to enter the Paris sewers, it is estimated that at least 60,000 hektares (150,000 acres) may be fertilized by it. On the other hand, the area necessary to purify the sewage of Paris, which amounts to 100,000,000 cubic meters (tons) annually, will amount to 2,000 hektares (5,000 acres) if 50,000 cubic meters (tons) are annually purified per hektare (2.5 acres), or to 3,000 or 4,000 hektares (7,500 to 10,000 acres) if the quantity purified is reduced to 33,000 or 25,000 cubic meters (tons) per annum. Thus the enormous difference between the areas required for the two processes is at once apparent.

The two processes differ also in other respects. Purification on a restricted area is governed by certain laws of distribution and drainage, with which it is quite difficult to comply. Utilization over large surfaces is almost entirely independent of such rules. Consequently, with the latter the time and the amount of an irrigation may be chosen at will. The cultivation of cereals and the rotation of crops become possible. When sewage is thoroughly utilized, the cultivation is the controlling element. Purification accompanies it in one way or another, without being attended to. When sewage is merely purified, that is nearly the sole result; cultivation being a secondary consideration.

In making these comparisons, however, allowance should be made for the different amounts of fertilizing elements which different kinds of crops are able to appropriate. Thus, in market gardening, the difference between the quantity which can be purified and that which can be utilized upon a given area is much less than when the calculation is based upon ordinary farming.

Some very interesting experiments were made at Paris upon the action of growing plants upon sewage during irrigation. Four masonry-lined tanks, 10 meters (33 feet) long and 8.50 meters (28 feet) broad, which had been constructed for experiments in the chemical purification of sewage, and which were completely water-tight, were prepared by laying tile drains upon

their bottoms. They were then filled to a depth of 1.80 to 2 meters (5.8 to 6.6 feet) with the ordinary soil of the Paris irrigation fields.

The amount of sewage supplied to these basins was carefully measured, as well as the quantity of water escaping from the drains, which had all filtered through the earth down to their level. Various plants, such as maize, beets, cereals, etc., were grown upon the surface of the basins, and the crops were weighed, when gathered, with the greatest care. An exact record was thus obtained of the amount of water supplied, the amount reaching the under-drains, and the amount absorbed and evaporated by the plants.

This highly interesting result was obtained: Out of 24,000 cubic meters (tons) supplied per hektare (2.5 acres) in six months, only 1,600 cubic meters (tons) reached a depth of 1.80 meters (5.9 feet); and, in a general way, M. Marié-Davy concluded from his experiments that out of a supply of 5,000 to 6,000 cubic meters (tons) per hektare (2.5 acres) per month, only 1-30th of the water supplied reached the subterranean drains. Vegetation consequently acts as a powerful upward drainage. The soil transforms the impure water supplied to it, oxidizes it, and makes of it an excellent liquid manure. The plants absorb the useful elements of this manure and yield to the atmosphere, by evaporation, nearly the whole of the liquid which has served to convey them. Thus purification and agricultural utilization perfect each other.

The effluent water from the basins, escaping by the subsoil drains, was found to be nearly chemically pure, only six grammes (93 grains) of organic nitrogen remaining out of 2,262 grammes introduced, and eleven grammes (170 grains) of ammoniacal nitrogen out of 10,597 grammes introduced.*

The following is the result of an analysis of the effluent water from the Paris irrigation fields at Gennevilliers: —

* Durand-Claye.

(*Parts per 100,000.*)

Sulphuric acid	24.9	Soda	6.6
Chlorine	6.5	Potash	1.0
Silica	1.2	Nitric acid	8.9
Peroxide of iron	0·2	Ammonia	Doubtful traces.
Lime	32.7	Loss by calcination	9.0
Magnesia	3.1	Carbonic acid, unmeasured matters and loss	17.9

Microscopical analyses of effluent waters are somewhat rare. The effluent water from the Paris irrigation fields, however, has been submitted to careful microscopic analysis. A comparison of the results obtained by microscopic analyses of various waters is given in the following table.*

NUMBER OF MICROBES CONTAINED IN A CUBIC CENTIMETER OF DIFFERENT WATERS.

	Average of 1879.	July 6, 1880.
Water condensed from the air		
Rain-water collected at Montsouris	35	
Water of the Vanne supplied to Paris	62	
Water from the Seine, above the Pont de Bercy	1,200	1,600
Water from the Seine, left bank near Asnières,		3,200
Effluent water from the Paris irrigation fields,		12
Paris sewage	20,000	

From this it is seen that the action of the soil has reduced the number of microbes from 20,000 per cubic centimeter (16.23 minims) to 12 per cubic centimeter, and that the effluent derived from the Paris sewage contained fewer microbes than the water supplied to Paris for domestic uses. But M. Marié-Davy adds:

"We think that had the effluent water from the Paris irrigation fields passed through as great a distance as does that of the Vanne before it reaches Paris, these two numbers, now different, would be very nearly the same. We may at least draw this conclusion from these experiments: That as regards microbes,

* Marié-Davy, Journal d'Hygiène, No. 202.

viewed as a whole and as susceptible of reproducing themselves in the nutritive liquors employed, the effluent water from the Paris irrigation fields is as pure as that of the Vanne; that is to say, that the purification by the soil is complete."

It has been urged, however, that as the microbes of sewage are intimately associated with excrementitious matter, there is danger that, however completely they may have been removed from the effluent water, the few remaining may cause the spread of disease, if the water containing them be used for domestic purposes. It has also been claimed that the exhalations from fields irrigated with sewage — the vapor from the sewage as well as the gaseous emanations from the soil — may cause the dissemination of microbes and malarial influences in the atmosphere, and consequently injure the health of those residing on or near the irrigation fields.

These questions have given rise to heated discussions among scientists. The following letter of Dr. Frankland to M. Mille, Inspecteur Général des Ponts et Chaussées, briefly states the case in its true light: — *

"In reply to your letter of the 12th inst. (May, 1881), I will say that I have followed with the most lively interest the recent researches of your illustrious compatriot M. Pasteur, and I consider them of the highest importance as regards the public health. I agree with him on this point, that the germs of various kinds of disease are probably governed by the same laws of development as ordinary bacteria and the poison of anthrax."

"These considerations, however, have not modified my opinion as to the harmlessness of sewage irrigation; for its harmlessness has been proved by ample experience, while the conditions favorable to, or destructive of, bacteria are as yet scarcely known; and it is not improbable that agents which are thought to be incapable of affecting the vitality of these organisms may have the power of rapidly exercising a fatal influence upon them, while other agents considered deadly to these same organisms may leave them untouched. It has been

*A. Durand-Claye, Observations des Ingenieurs, 1881.

recently proved by experiments in my laboratory, that although bacteria live and multiply in sulphuric acid, in cyanogen and other deadly poisons, they are at once destroyed by that inoffensive material, metallic iron."

"That there may be, in nature, powerful agents for the destruction of the germs of disease, cannot be doubted; otherwise the human race would, long since, have been exterminated. These agents are, for the most part, unknown, but experience seems to show that some of them are active in the process of sewage irrigation; for it has been demonstrated many times in this country (England), that sewage, *even when infected by cholera and typhoid fever*, has never, when used in irrigation, transmitted disease, either to those living on the irrigation fields, or to those who consume the crops raised upon them; although, I admit, that at first sight one would be disposed to expect the contrary."

The practice of applying large quantities of sewage to limited areas, when purification is the sole result sought, has received the name of "Intermittent Downward Filtration," which was given it by the Rivers' Pollution Commission of 1868. This method, when carried to excess and to the exclusion of vegetation upon the area irrigated, has not given satisfactory results, owing to the difficulty of regulating the amount of sewage applied, resulting frequently in the saturation of the soil.

J. Bailey Denton, C. E., one of the strongest advocates of this process, writes:* "In speaking of 'intermittent filtration,' I do not refer to the practice of crowding sewage *continuously* on porous land in the careless manner often adopted to get rid of sewage, and which results in its collection in hollows and low places to injure growing crops, to depreciate the effluent, if there be any, and to cause a nuisance on the surface of the land, but I refer to the concentration of sewage *at regulated intervals* on as few acres of land as will absorb and cleanse it, without preventing the production of vegetation."

The methods adopted for applying sewage to the land are

* Ten Years' Experience, etc.

generally simple. As a rule, the distribution is better effected by temporary expedients than elaborate and costly arrangements.

The sewage is conducted to the highest points of the land to be irrigated, either by pumping or by gravity. This portion of the work, being of a permanent character, may be constructed of cast-iron pipes, brick-work, concrete, or other durable materials. Some of the principal lines of "carriers" or channels may also be of a permanent nature. The minor channels are usually simple trenches in the earth. Their position may then be easily changed according to the needs of cultivation; and it is considered better practice, in some methods of distribution, to transpose the position of the carriers and beds each season so as to equalize the purification of the sewage more perfectly. Sometimes, as at Dantzic, the sides of the small carriers are protected with coarse wicker-work, but usually the earth has sufficient coherence to render artificial protection unnecessary.

The system according to which the sewage is distributed is determined partly from the topographical features of the soil and partly from the character of the crops to be raised. The system called "Broad Irrigation" contemplates the spreading of the sewage in a broad sheet, constantly flowing over the surface of the land during each watering.

The carriers for this method are nearly level and approximately follow the contours of the ground. They are frequently placed in several tiers, forming what is termed the catch-water system; the second tier of carriers receiving the overflow from the land watered by the upper carriers, and, in their turn, distributing to the land below them.

The surface of the land should be prepared so that there may be no hollows where the sewage may become stagnant. On the other hand, the surface should not have such an inclination as will cause the sewage to flow off too rapidly. It should remain upon the land long enough for the purifying agencies to perfect their work.

Circumstances sometimes favor the division of the ground into alternate elevations and depressions between two parallel lines of main carriers. Secondary carriers upon the ridges per-

mit the sewage to overflow upon either side and to flow down the depressions to furrows at their bases, which conduct the surplus liquid to the lower main carrier, from which the process is repeated. Whenever practicable, the distance between the ridge and the furrow should be such that most of the sewage may be absorbed upon the slope, little or none reaching the midway furrow.

Mr. J. Bailey Denton writes: "Mr. Hope, who has arranged his land at Breton's (which is of a porous character) on the 'lands' system laid as flat as practicable, has declared that 'the most convenient size of land is forty or forty-five feet wide from furrow to furrow, with a slope of one in twenty from furrow to ridge.' In clayey, loamy lands it is probable that double the width may be adopted without increasing the height of the ridge, and this would make the rate of inclination one in forty instead of one in twenty. The character of the soil governs the inclinations of the slopes to be formed for receiving the sewage. If the soil is very porous, and particles naturally coarse, the inclination must be steeper than where the soil is naturally retentive and the particles fine."

"The larger the bed or slope that will absorb the sewage without waste the better, as it can be more economically served with sewage, and it should always be borne in mind that the larger the space devoted to individual crops the greater will be the profit, the farmer's labor being reduced proportionately to the increase of area. Every case, however, must be treated on its own specialties, and it is better to act on a tentative plan rather than determine with precision beforehand what the size and inclination of the slopes or beds should be."

The "Flat-bed System" of distribution is well adapted for market gardening. In this system the ground is divided by furrows into narrow beds having a width of from three to twelve feet, depending upon the porosity of the soil and the nature of the crops. Contrary to the system just described, the sewage runs in the furrows. The vegetables grow upon the top and sides of the narrow beds, and receive their supply of moisture and nutriment by the percolation of the liquids through the soil, the sewage never being applied to the leaves or stalks of

the plants. The furrows are from eight to sixteen inches in depth, according to their importance. Their length should be such that the sewage may be nearly all absorbed in running from one end to the other. In a sandy gravel this will occur after a run of from one hundred to one hundred and fifty feet. In clayey soils the absorption is slower and the sewage may sometimes be used, with advantage, upon several beds in succession.

The frequency of the waterings depends upon the nature of the crops, the weather, and the season of the year. With a warm climate, a permeable soil, and rapidly growing plants, frequent and abundant waterings are needed. At the Paris irrigation fields, where market gardening is extensively carried on, the waterings occur every three days, on an average. The soil being very permeable, the farmers thus use from 40,000 to 50,000 cubic meters (tons) of sewage per hektare (2.5 acres) per annum. In winter the waterings take the form of broad irrigation.

All solid substances are generally removed from the sewage before it is applied to the land. This is done by passing it through coarse strainers. In one arrangement, patented by Mr. Baldwin Latham, a vertical strainer, rotating about a horizontal axis, collects all solid matters in a receptacle, from which they are raised by an Archimedean screw and deposited in a wheelbarrow. This is in use at Dantzic, Croydon, Coventry, and other places. In rare instances the entire volume of sewage is strained through a coke filter, as at the "Croydon Rural" Sewage Works, where the sewage is thick and dark colored.

The distribution of the sewage is controlled by movable dams of wood or iron, which are set at any desired place in the carriers. The flow of sewage being thus stopped, the carrier soon fills to the top and overflows upon either side, in the case of broad irrigation, or supplies lateral carriers in the ridge-and-furrow and flat-bed systems.

These dams are of the simplest possible construction, frequently being mere plates of galvanized iron fitted with a handle and shaped to fit the form of the carrier. They are pressed into the earth after the manner of a spade. Brick and

concrete carriers are supplied with grooves to receive these dams. Carriers that are under pressure, as at Paris, are supplied with simple plates that are screwed down upon the orifice of discharge, which is horizontal and at the top of the carrier. In these mechanical appliances, simplicity and economy of construction are essential features.

No difficulty is reported to exist in disposing of sewage by irrigation during winter, either on the Continent or in England. In Germany, where the climate is similar to our own, as at Dantzic and Breslau, the irrigations are reported to be uninterrupted in winter by the frost. Vegetation not existing in winter, the purification of the sewage is effected solely by the action of the soil.

The temperature of sewage has been frequently observed at different seasons of the year, and it has been found to be relatively warm in winter and cool in summer.

At Dantzic the temperature of the sewage is said not to fall below forty degrees Fahrenheit at the pumping station, and forty-two degrees at the point of delivery to the irrigation fields. Its temperature in summer is said not to rise above fifty-nine degrees at the pumps and forty-eight degrees at the outlet. Between the pumping station and the irrigation fields the sewage is conveyed in three siphons beneath the Vistula and the ditches of the fortifications, and is carried under ground in closed pipes to the irrigation fields. The effect upon the temperature of the sewage, of its deep passage beneath the river, is seen in its higher temperature in winter and lower temperature in summer at the irrigation fields. The irrigations are continued throughout the winter at Dantzic without interruption, in spite of the severity of the climate. The sewage is said to arrive at the irrigation fields at a temperature of forty-two degrees Fahrenheit, even during the greatest frosts. It melts the snow and ice, and continues to percolate into the ground, without causing trouble to the tenant of the farm.

The severity of the winters at Dantzic is such that the ground freezes from one to three feet deep. Water pipes are laid five feet under ground. The temperature of the air falls at times to eleven degrees below the zero of Fahrenheit. Snow falls as

early as October and as late as April. The rivers at Dantzic are frozen from the middle of November till the last of April. It should be observed that the soil of the Dantzic irrigation fields is extremely porous.

The following table gives the mean monthly temperatures at Dantzic for eighty-one years, observed, together with the mean monthly temperatures at Providence for the forty-eight years, from 1832 to 1876 plus 1881 to 1883 inclusive.

Month.	Mean Temperatures.	
	Dantzic.*	Providence.†
January	26.8	26.78
February	29.1	27.33
March	32.4	33.90
April	41.2	44.50
May	50.4	55.14
June	58.3	65.15
July	62.8	70.69
August	61.9	68.78
September	54.5	61.17
October	44.1	50.74
November	36.3	40.00
December	30.0	29.73

At Breslau, where the winter is nearly as severe as at Dantzic, no trouble is said to be experienced from frost at the irrigation fields, although the soil is not as porous as at Dantzic. The frost enters the ground from two, to four and one half feet deep at Breslau, and the temperature of the air at times falls to four degrees below the zero of Fahrenheit.

The following facts were observed as to the temperature of the sewage of Paris during the extremely cold month of December, 1879: — ‡

"While the mean temperature of the air was 18.3° F., and while the water of the Seine was constantly at 32° F., the mean temperature of the sewage was 43° F.; its temperature,

* "Danzig . . . Beziehung."

† From 1832 to 1876 inclusive, records of the late Prof. Alexis Caswell of Brown University; from 1881 to 1883 inclusive, records in city engineer's office.

‡ Durand-Claye, Comptes Rendus de l'Académie des Sciences.

even during the greatest frosts, remained between 41° and 45.5° F. This peculiarity was noticed in 1868, but it had not been observed before under circumstances so decisive. It is due to the warming which the coldest water receives while flowing in subterranean channels, such as the sewers of Paris, the average duration of the flow of the sewage from the inlets to the outfall into the Seine at Clichy being about four hours."

"In the intercepting sewer from the left bank of the Seine, which passes under the 'quartier de l'Etoile,' in a deep tunnel, and does not unite with the intercepting sewer from the right bank of the Seine until it arrives at Clichy, the temperature of the sewage was nearly four degrees higher (42.8° and 44.6° as compared with 39.2° and 41°) than in the intercepting sewer from the right bank."

"The same thing, but under peculiar circumstances, was noticed in another intercepting sewer which only carries about one fifth of the sewage of Paris, leaving the city at the Porte de la Chapelle, and discharging either upon the irrigation fields at Gennevilliers, or into the Seine at St. Denis. The sewage in the main line of this sewer, which serves Montmartre and La Chapelle, had a temperature of 39.2° to 43.7° F., analogous to that in the great intercepting sewer at Clichy. But at the Porte de la Chapelle it receives a branch which passes through the entire industrial quarter of La Villette and La Chapelle. In this branch, the water from condensed steam and the waste liquids from manufactories produced a temperature of 55.4° to 66.2°, while below the junction the temperature of the sewage was maintained between 53.6° and 62.6.°"

"In consequence of the high temperature of the sewage, it continued to be used for agricultural purposes during the severe frosts of December. Early in the month, it was thought that no one would wish to irrigate during such cold weather and while so much snow was on the ground, and orders were given to stop pumping the sewage to the irrigation fields. But some of the farmers petitioned for a continuance of the pumping, in order that their fields might be cleared of snow by the thawing caused by the sewage, thereby giving them an opportunity to gather certain crops, such as leeks, cabbages, etc."

The town of Pullman, Ill., disposes of its sewage by irrigation, upon a tract of alluvium overlying a subsoil of clay, some three miles distant from the town. No trouble is reported to have arisen in winter on account of frost. Sewage irrigation has also been practised on a small scale at several asylums and summer resorts in this country, but no trouble from frost has been reported.

From what has been already written upon the theory of the purification of sewage by applying it to the land, it is evident that the amount of land required in any given case will depend upon its character as well as upon the amount and quality of the sewage. It is not practicable to formulate any general rule. Sir Robert Rawlinson writes: — *

"The areas which have been found in practice to answer are as under stated, namely, for broad irrigation about one statute acre to each one hundred of population of a fully water-closeted town; where tanks separate solids, and the fluid is clarified by chemicals, one acre of land prepared as a land filter may serve for five hundred of population; but there cannot be any hard and fast rules, as one mode and one area may be successful in one place and may be stated to fail in another; much will depend upon management."

One acre of land to each one hundred of population will allow the use of the sewage for agricultural purposes. In proportion as it is possible to confine the action of the land to purification only, its area may be reduced, according to the principles already given.

The following table gives the amount of land in use in several of the cities visited in Europe for the purposes of this report: —

* Suggestions (etc.), 1878

Name of Town.	Population from which sewage is collected.	Dry-weather flow of sewage per day.	Area of land to which sewage is applied.	Number of population of town to one acre of sewaged land.	Imperial gallons of sewage per acre of sewaged land.	Nature of soil.
		Imperial gallons.	Acres.			
Bedford,	22,000	1,000,000	155	142	6,451	Porous
Breslau,	300,000	7,707,500	741	400	10,397	"
Croydon,	65,000	4,700,000	450	144	10,444	"
Dantzic,	100,000	3,063,700	395	250	7,749	"
Doncaster,	24,000	600,000	200	120	3,000	"
Leamington,	26,000	800,000	375	69	2,133	"
Oxford,	41,000	1,250,000	318	128	3,931	"
Warwick,	12,000	1,000,000	130	92	7,692	Clay
Wimbledon, After precipitation with lime.	20,000	560,000	61	328	9,180	Porous
Wrexham,	10,000	400,000	80	125	5,000	"

The amount of land at Breslau will soon be increased to about 2,000 acres; the soil at Dantzic is extremely porous; at Wimbledon the solids are extracted from the sewage by the action of lime, only the effluent being applied to the land. Throwing out these three cases, we obtain an average of one hundred and seventeen persons and 5,521 imperial gallons per acre of sewaged land.

A statistical table of nineteen towns in Great Britain, prepared by Prof. Henry Robinson,* gives the following averages: —

One hundred and thirty-seven people to each acre irrigated.
One hundred and ninety-five acres to each million imperial gallons of sewage (or 5128 imperial gallons per acre).
Thirty-eight imperial gallons of sewage per head of population per day.

A statistical table prepared by H. U. McKie, city engineer of Carlisle, England, for that city, gives ninety-eight as the average number of inhabitants to each acre irrigated, as deduced from the statistics of fifty-three towns in Great Britain, and 3,826 imperial gallons of sewage per acre per day, as deduced from the statistics of thirty-three towns.

A portion of the land available for irrigation is usually reserved for a land filter to receive the excessive amounts of

* Sewage Disposal p. 79.

sewage sometimes delivered in times of heavy rain. The land filter should be upon that portion of the land which is best adapted to the purification of sewage. Its surface should be carefully graded, and it should be thoroughly under-drained if necessary. Such land filters are frequently planted with willows or "osiers."

The amount of crops raised upon sewage farms is very considerable. Four or five crops of grass are reported in many instances. This grass is usually used in the green state. The variety called Italian rye grass is largely grown upon sewage farms, as it absords a large amount of moisture. Roots and market-garden vegetables attain a large size when cultivated with sewage, and are of excellent quality. The amount of crop per acre is also very large, as may be seen from the statistics of the towns visited, which may be found in Appendix B.

The financial results of sewage farming depend greatly upon local circumstances and management. It is said that the income from sewage farms will sometimes pay for the cost of operating them. If, however, the annual expenses of interest, sinking fund, and the pumping of sewage be charged against the farm, this should not be expected.

THE DISPOSAL OF SEWAGE BY PRECIPITATION.

The various methods adopted for the clarification and purification of sewage, other than by applying it to the land, may be classed either as subsidence, mechanical filtration, or chemical precipitation.

Subsidence.

Subsidence consists in permitting the sewage to come to comparative or absolute rest in suitable tanks, where the solids and a portion of the flocculent matters are deposited by gravitation. The effluent water contains all the dissolved impurities, and usually some of the flocculent matter and solids, such as straws and other light substances. The process is merely a palliation of the sewage nuisance, by keeping the greater part of the solids of the sewage out of the streams into which the effluent flows. The effluent is highly putrescible, and besides containing some of the most valuable manurial ingredients

of the sewage, which are lost, may itself cause a nuisance in the stream into which it flows. The odors about the subsidence tanks are sometimes very offensive.

Mechanical Filtration.

Mechanical filtration consists in straining the sewage through suitable materials, either alone or in connection with depositing tanks. The materials which have been used to filter sewage are very numerous. The following are a few of the combinations that have been used for this purpose: "Wicker frames filled with gravel; animal and vegetable charcoal with gravel; straw, ashes, dry earth, burnt clay, sand, and heath arranged in ten beds; beds of broken stone and fine gravel; boxes of perforated boards filled with burnt earth, etc., cocoanut matting filters filled with gravel; sawdust, etc., etc."

This process effects a more perfect separation of the solids and clarification of the sewage than is obtained by simple subsidence in tanks. The effluent, however, possesses the same objectionable characteristics that have just been mentioned in connection with subsidence.

The filtration of sewage is rendered difficult by the slimy nature of that liquid; the effect of this peculiarity being to produce a film of foreign matter upon the surface of the filter, which gradually clogs it and prevents its effectual working. This necessitates a frequent renewal of the filtering materials. In the Farquhar-Oldham filter the process is accelerated by a scraper which continually removes those portions of the filtering material which have become inoperative.

The clarification of sewage by subsidence or by mechanical filtration is practised at but few places. These processes are giving way to better methods.

Chemical Precipitation.

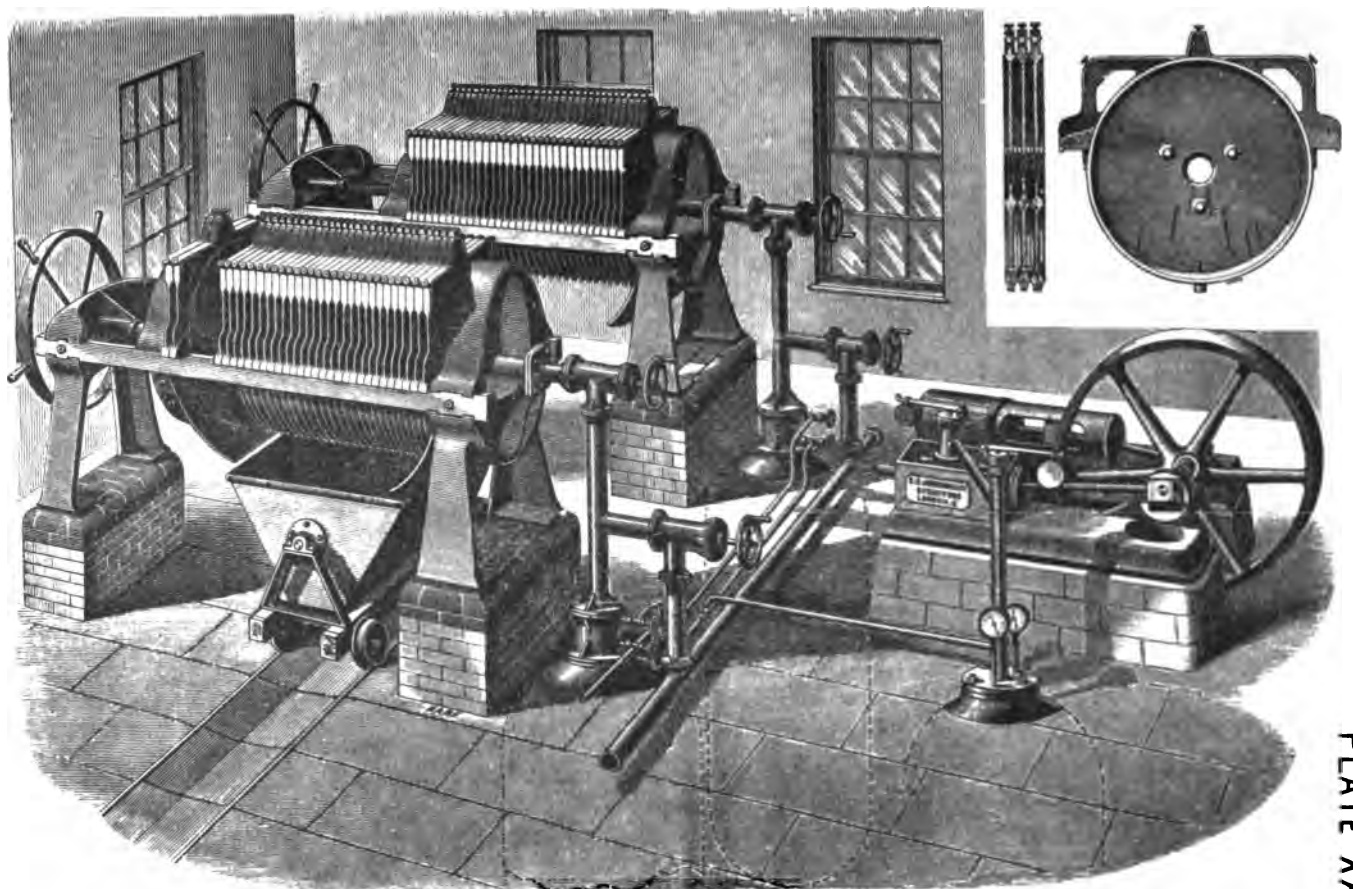
Chemical precipitation, as the name indicates, consists in adding to the sewage a solution of certain chemicals whose action is to promote the deposition of the solid, and of a portion of the dissolved matters in the sewage. The chemicals.

also act as deodorizers, and to a certain extent as disinfectants, thereby rendering the works nearly devoid of offensive odors; thus contrasting strongly with the method of simple subsidence by gravity.

The mixture of sewage and chemicals flows into precipitation tanks, where it comes to comparative or absolute rest, and from which the effluent flows after the chemical action has taken place, leaving such impurities as have been removed. These impurities, together with the liquids retained by them, form a black fluid which is denominated "sludge." About ninety per cent of this sludge is water, the remaining ten per cent being the impurities obtained from the volume of sewage treated.

The disposal of the sludge is a difficulty inherent to precipitation works. In its original condition, containing a large amount of water, it is too fluid to bear transportation in the ordinary manner. It is pumped out of the precipitation tanks and allowed to flow, in some instances, upon the adjacent land, where it remains until it loses sufficient moisture by evaporation to allow it to be cut with a spade. To effect this evaporation by exposure to the air requires a great deal of time, during which the sludge gives off certain odors in warm weather which have caused complaint.

Various means have been tried to hasten the consolidation of the sludge by artificial means, as by drying upon heated floors after a partial draining off of the liquids. The most successful method, however, is that recently perfected by Messrs. S. H. Johnson & Co., of Stratford, England. By this method the liquid portion of the sludge is extracted by pressure in a press of peculiar construction. The press (Plate 23) is provided with a set of "cloths" of stout canvas, which are held together by plates in such a way as to form a series of compartments, into which the sludge is forced by the pressure of compressed air, the liquids escaping through the meshes of the cloth, and the solids being retained within the compartments formed by the cloths. When all the compartments are filled with the solid substances, the press is opened, and within each compartment is found a solid cake of compressed sludge, nearly devoid of odor and of such compactness that it can be readily handled.



Johnson's Filter Press.

PLATE XXIII

The amount of water in the cake is about fifty per cent of its weight. That is to say, one hundred pounds of solid matter, for example, when precipitated from the sewage, entangles within itself about nine hundred pounds of water, forming a liquid sludge. The action of the press is to extract about eight hundred pounds of the water, leaving the one hundred pounds of solids associated with about one hundred pounds of water in the cake of compressed sludge. The liquid extracted from the sludge runs back into the sewer, and passes through the precipitation tanks again.

This recent method of treating sludge has removed a great objection to chemical precipitation. The compressed sludge may be used for manure, it possessing considerable fertilizing value, depending upon the nature of the sewage and of the chemicals used, or it may be used for reclaiming land or for other purposes.

The general features of precipitation works may be briefly summarized: mechanical arrangements for separating the grosser solids from the sewage; others for disolving the chemicals and incorporating them with the sewage; tanks of sufficient area and capacity for the precipitation of the impurities, and with channels for the escape of the effluent; pumping machinery for removing the sludge, and suitable arrangements and machinery for its disposal; buildings for the protection of the works, for the storage of materials, and for the residence of the employés. To these may be added certain facilities for the control of the sewage, both at ordinary times and also in case of severe storms, when its volume may exceed the capacity of the precipitation tanks. At such times the sewage being greatly diluted with surface water, the excess may be sent directly to the river through overflow weirs, as has been before observed.

While these general features are common to all precipitation works, the variations in detail, and in particular as to the kind and amount of chemicals used, are very great. The following is a brief list of some of the more important chemical methods that have been tried: —*

* Robinson and Melliss, Purification of Water-carried Sewage, 1877.

1. — *Processes that employ Salts of Alumina as the chief precipitating agent.*

The Coventry process. Crude sulphate of alumina, salts of iron, and lime.

The Native Guano, or A. B. C. process. Alum, blood, clay, and animal charcoal.

The Phosphate sewage process, patented by Mr. David Forbes and Dr. Astley P. Price. Phosphate of alumina and lime.

Bird's process. Sulphuric acid and clay.

Stothert's process. Lime, sulphate of alumina, sulphate of zinc, and charcoal.

2. — *Processes which employ Lime as the chief precipitating agent.*

Hille's process. Lime, tar, salts of magnesium, etc.

Marsden & Collins's process. Lime, carbon (a waste product of prussiate of potash manufacture), house ashes, soda, and perchloride of iron.

Holden's process. Sulphate of iron, lime, coal-dust, and clay.

Fulda's process. Lime and sulphate of soda.

Blythe's process. Superphosphate of lime, with magnesia and lime.

Whitthread's process. Dicalcic and monocalcic phosphate and milk of lime.

Campbell's process. Soluble phosphate of lime.

Hanson's process. Lime, black ash, and red hematite treated with sulphuric acid.

Goodall's process. Lime, animal carbon, ashes, and sesqui-persulphate of iron.

The Lime process. Milk of lime.

General Scott's process. Milk of lime; the sludge being burnt, forming Portland cement.

3. — *Processes in which Salts of Iron are used as precipitants.*

Chloride of iron and lime.

Sulphate of iron and lime.

4. — *Miscellaneous processes.*

These processes are very numerous, but have led to no practical results. In England, from 1856 to 1876, there were 417 patents issued, all more or less connected with sewage and manures.*

Of the many methods that have been tried for the chemical treatment of sewage, there are but three that stand prominent at the present time. These processes are those of —

The Rivers' Purification Association, limited,— better known as the Coventry process;

The Native Guano Company, limited, — better known as the A. B. C. process; and

The Lime process.

The Coventry Process.

The Rivers' Purification Association, limited, which was formed in 1877, "does not confine its operations to any particular system for treating sewage, but employs whatever is found to be most suitable and best adapted to the local circumstances and requirements of each place."

Although acting upon this basis, the process employed at works which the company is now operating is what is known as the Coventry process of chemical precipitation, the chemicals used being crude sulphate of alumina, proto-sulphate of iron, and lime. The company at the time of our visit in England was operating the sewage purification works at Coventry, Hertford, and Leyton, and their process has been recommended for the sewage works of the Lower Thames Valley Main Sewerage District; which if carried out will embrace the sewerage systems of fifteen or twenty towns in the immediate vicinity of London.

At Coventry the effluent from the precipitation tanks is still further purified by filtration through land before it flows into the river Sherbourne. At Hertford the effluent is filtered through coke filters. At Leyton the effluent flows directly into the stream, which is a branch of the river Lee, without any filtration whatever.

* Report of Local Government Board, 1876.

The appearance of these effluents is excellent. They are nearly, if not quite, colorless and possess little or no odor. Their chemical analyses indicate a high degree of purity. The following table gives the results of several analyses of the effluents at Coventry and Hertford, made by Prof. Wanklyn: —*

Place.	Date.	Grains per [imperial] gallon, [or parts per 70,000.]		[Milligrammes, per kilo, or] parts per million.	
		Solids.	Chlorine.	Free ammonia.	Albumenoid ammonia.
	1878.				
Coventry.	June 1	. . . .	4.8	. . . .	1.60
	July 22	. . . .	4.2	18.00	1.00
	Sept. 24	. . . .	4.6	14.00	2.00
	1880.				
Hertford.	Jan. 7	. . . .	1.5	1.20	0.14
	May 28	. . . .	1.4	1.20	0.10

The works at Leyton have been established quite recently, and no analyses of the effluent have as yet been published.

The sludge obtained by the Coventry process has considerable manurial value. Dr. Voelcker† estimated its theoretical value at 16*s.* 9½*d.* per ton, and its practical or market value as compared with farm-yard manure at 5*s.* 6*d.* to 8*s.* 4*d.* per ton. These values refer to sludge containing from fifty to sixty per cent of moisture. Were the moisture still further reduced by drying, the computed value would be somewhat greater. Dr. Wallace estimated its value when air dried, and containing about ten per cent of moisture, at £1 7*s.* 2*d.*‡ The price obtained for it, however, is very much less than these values, which have never been realized. At Coventry and Leyton the sludge, pressed into cakes containing about fifty per cent of moisture,

* Reports of Rivers' Purification Association.

† Local Government Board Report, 1876.

‡ Glasgow Sewage Report, 1879.

is sold at from 2*s.* to 2*s.* 6*d.* per ton. The demand for it, however, is not large.

The A. B. C. Process.

The A. B. C. process operated by the Native Guano Company, limited, has been before the public for many years. The process is named from the initials of several of the most important ingredients used, — alum, blood, and clay. The process is now in operation at Aylesbury, Buckinghamshire, England, a town of about eight thousand inhabitants. It has also been tried in Leeds, Leicester, Leamington, London, and Paris, but its use has been discontinued in all except Aylesbury. At Leeds and Leicester the lime process has been substituted, being cheaper; the effluent produced, although not as good as that obtained by the A. B. C. process, being notably superior to the filthy river water into which it flows. At Leamington and Paris, irrigation has been finally adopted. At London, the sewage continues to be discharged into the Thames without any treatment whatever.

The Native Guano Company, being in the position of contractors, are unwilling to publish details of materials, cost, etc., which vary somewhat according to the requirements of each particular case. The original specification for the A. B. C. patent contained the following list of ingredients:* "Alum, blood, clay, magnesia or one of its compounds — by preference the carbonate or the sulphate, manganate of potash, or the compound of manganese, burnt clay otherwise known as ballast, chloride of sodium, animal charcoal, vegetable charcoal, and magnesian limestone. Of these substances, the manganese compound, the burnt clay, chloride of sodium, and magnesian limestone may be omitted, and it is not essential that both animal and vegetable charcoal should be used."

"The proportions in which the ingredients are to be used vary according to the nature of the sewage to be purified. For ordinary sewage the following proportions have answered well: —

* Rivers' Pollution Commission, Report on A. B. C. Process, 1870.

Alum	600	parts
Blood	1	"
Clay	1900	"
Magnesia	5	"
Manganate of potash	10	"
Burnt clay	25	"
Chloride of sodium	10	"
Animal charcoal	15	"
Vegetable charcoal	20	"
Magnesian limestone	2	" "

The proportions in use at Aylesbury are understood to be as follows: —

Twelve hundred weight of clay containing forty per cent of moisture.

Twelve hundred weight animal charcoal containing fifty per cent of moisture.

Five and one half hundred weight alum (crude).

Fourteen pounds of "blood-clay," containing about seven pounds of blood and seven pounds of clay.

The animal charcoal, blood, and clay are dissolved together in sufficient liquid (generally sewage), and afterwards flow in a small channel which discharges into the sewer a short distance above the precipitation tanks. The alum is dissolved in a separate vat in sufficient liquid (generally sewage), and flows by another channel which discharges into the sewer a few feet below the point of discharge of the first channel. The ingredients then flow with the sewage in a mixing channel which leads to the precipitation tanks. These are three in number. The sewage passes through them in succession by a circuitous course, most of the impurities being precipitated in the first tank. The effluent overflows from the third tank into a channel paved with white tiles to render the purity of the effluent more obvious to the eye. This channel leads to the river, into which the effluent is discharged. The effluent is not filtered in any way. At the time of our visit it was nearly colorless, there being a faint yellow tinge and a slight tendency to froth. Its appearance was in marked contrast with the dark sewage approaching the

works. The works were entirely devoid of objectionable odors.

The sludge is pumped from the precipitation tanks into an elevated reservoir, from which it passes to the sludge presses, where it is pressed into cakes. These cakes are afterwards dried (a little sulphuric acid being first added to fix the ammonia), ground into powder, packed in bags, and sold under the name of "native guano."

The following is a copy of a report of Prof. Wanklyn on the chemical composition of the effluent at Aylesbury: — *

"*Report on six samples of the effluent water from the Native Guano Company's Works at Aylesbury.*

"On Monday, Oct. 4, 1880, and on the five following days, samples of the effluent water discharged by the Native Guano Company's Works at Aylesbury were collected by Mr. Cooper and my officers, acting under the Sale of Food and Drugs Act.

"The following are the results of the analyses of the samples: —

Date of collection of the sample.	Grains per [imperial] gallon [or parts per 70,000].		[Milligrames per kilo, or] parts per million.	
	Total solids.	Chlorine.	Free ammonia.	Albumenoid ammonia.
Oct. 4	43.	6.1	22.00	0.76
" 5	41.	3 5	12.10	0.60
" 6	43.	2.7	5.80	0.36
" 7	34.	2.7	4.80	0.32
" 8	34.	2.5	4.10	0.20
" 9	54.	3.5	5.00	0.40

"Any of these effluents may be with safety discharged into a river.

"Regarded as effluents, all of these waters are good; the least favorable being about on a par with the river Thames at London Bridge, and the best being as little impure as the unfiltered water high up the river.

* Native Guano Company's Publications.

"The circumstance that there were floods during the week in which the samples were taken, renders the test to which the company's operations have been subjected especially severe.

"In conclusion I have to record my belief, based on my analytical investigations, that the company's process as carried out in Aylesbury is most successful in purifying sewage."

(Signed) J. ALFRED WANKLYN,

Laboratory, 7 Westminster Chambers, London, S. W.

Nov. 8, 1880.

It is stated by the Native Guano Company that fish will live in the effluent produced by the A. B. C. process. They were awarded a "silver medal and a prize value £20" at the National Fisheries Exhibition at Norwich, in 1881, "for their exhibit of process for rendering innocuous to fish-life streams polluted by sewage and chemical or other works." They were awarded "a gold medal and a diploma of honor" at the International Fisheries Exhibition, London, 1883, "for purification of sewage."

The Native Guano Company state that the price of the product or "native guano," made from the sludge, is seventy shillings per ton at the works. This value is more than double that estimated from chemical analysis. Dr. Voelcker estimated the theoretical money value of the sludge obtained from the sewage of Leeds by the A. B. C. process, when containing 15 per cent of moisture, at 16*s.* 8½*d.*, and the value of the same as compared with farm-yard manure, at from 5*s.* 6*d.* to 8*s.* 4*d.* per ton.* Dr. Wallace estimated the value of the sludge obtained from the sewage of Aylesbury, by the A. B. C. process, in 1879, when containing about 12 per cent of moisture, at thirty-three shillings per ton. The fact that the fertilizer made from the sewage sludge at Aylesbury sells for a higher price than is indicated by chemical analysis has, we believe, never been satisfactorily explained, the price obtained for such manures being usually less than that estimated from analysis. That it has been

* Local Government Board Report, 1876.

found to possess a high value as a fertilizer is attested by numerous testimonials.

The Lime Process.

The lime process is one of the oldest methods of purifying sewage by chemical precipitation. It is very extensively used where lime is cheap and where a high degree of purity in the effluent is not desired. It is in use at the present time at Birmingham, Bradford, Leeds, Burnley, Leicester, and at other places.

The plan of operation is usually to slake the lime, grind it, mix it with sufficient liquid (generally sewage) to form a milk of lime, which flows into the sewer and mingles with the sewage. The amount of lime used is about one ton to a million gallons of sewage. The sewage then flows into tanks, in which the precipitation takes place.

The effluent from the lime process is usually clear, but contains a large proportion of dissolved impurities in a condition favorable to subsequent putrefactive changes. When too large a quantity of lime is used, the effluent contains a surplus of free lime which is destructive to fish life. At Birmingham the effluent from the precipitation tanks is still further purified by land irrigation; about 500 acres of land are now under irrigation, and the area will soon be increased to 1100 or 1200 acres.

The following table, from a report of Dr. Wallace to the magistrates and council of the city of Glasgow,* gives the results of analyses of the effluents at Bradford, Leeds, and Birmingham, where the lime process is used, and at Coventry and Aylesbury: —

* Report by the Deputation appointed by the Magistrates and Council of Glasgow, 1880.

COMPOSITION OF RAW AND PURIFIED SEWAGE FROM VARIOUS ENGLISH TOWNS.

Grains per [Imperial] Gallon [or parts per 70,000.]

	In Solution.											Sedimentary Matter.		
	Total solids.	Saline matter.	Organic matter, etc.	Chlorine.	Equal to Chloride of sodium.	Oxygen required to oxidize organic matter.	Ammonia. Free.	Ammonia. Organic.	Ammonia. Total.	Nitrites.	Free lime.	Total.	Mineral.	Organic.
Bradford Sewage	52.64	41.16	11.48	4.13	6.80	.980	.840	.161	1.001			33.32	12.34	20.98
Bradford Sewage, after lime	124 60	110.60	14.00	4.34	7.15	1.015	.875	.168	1.043	Large.	54.58	146.90	114.80	32.10
Bradford Sewage, effluent from tank	91.28	82.74	8.54	3.64	6.00	1.190	.470	.105	.575	Large.	32.06			
Bradford Sewage, filtered through coke	61.04	53.62	7.42	3.64	6.00	1.120	.420	.098	.518	Large.	14.76	4.01	4.01	
Leeds Sewage	48.58	39.34	9.24	5.53	9.12	.875	1.035	.182	1.267			24.37	9.87	14.50
Leeds Sewage, mixed with lime	42.42	35.42	7.00	6.16	10.15	.840	1.035	.168	1.253	Considerable.	2.08	36 84	25.18	11.66
Leeds Sewage, effluent from sixth tank,	33.32	28.56	4.76	4.76	7.85	.682	.560	.105	.665	Large.	1.01	3.95	3 95	
Leeds Sewage, final effluent	34.86	29.26	5.60	4.69	7.73	.952	.525	.105	.630	Large.	1.01	2.46	2.46	
Birmingham Sewage	102.34	80.64	21.70	21.77	35.92	8.512	2.415	.476	2.891			31.23	16.29	14.94
Birmingham Sewage, effluent	55.72	47.18	8.54	12.18	20.09	1.386	1.470	.175	1.645	Small.	3.04	.92	.68	.24
Birmingham Sewage, effluent from land irrigation	50.26	38.50	11.76	5.74	9.47	.175	.201	.042	.243	Considerable.	10.59	Trace.		
Coventry Sewage	41.30	33.88	7.42	4.83	7.97	.423	1.820	.196	2.016	Trace.		14.81	6 48	8.33
Coventry Sewage, effluent	45.22	38.08	7.14	3.43	5.66	.294	.805	.098	.903	Considerable.		2.65	1.42	1.23
Coventry Sewage, effluent after filtration through land	44.94	38.78	6.16	3.85	6.35	.178	.647	.035	.682	Considerable.		3.58	2.90	.68
Aylesbury Sewage	49.14	40.74	8.40	4.97	8.19	.700	3.430	.147	3.577			594.98	456.73	138.25
Aylesbury Sewage, effluent from first tank	48.86	41.38	7.28	4.55	7.50	.385	1.470	.126	1.596			.98	.46	.52
Aylesbury Sewage, effluent from second tank	48.02	42.42	5.60	3.85	6.35	.245	.980	.126	1.106			.55	.31	.24
Aylesbury Sewage, final effluent	49.98	44.38	5.60	4.06	6.69	.231	1.190	.112	1.302					

The amount of sludge produced by the lime process is very much greater than that produced by the Coventry or A. B. C. processes. Its nature, moreover, is such that it is liable to putrefy and evolve offensive gases if it is exposed to the air and heat for a great length of time. Although possessing some value as a fertilizer, it is not much sought for by farmers. At Birmingham, it was formerly sold to a limited extent at £1 for twenty-five tons of sludge, dried to the consistency of moist earth. At the present time very little is sold there. The sludge is raised from the tanks by bucket pumps, which discharge into long wooden troughs, through which it flows, partly by gravity and partly by being pushed along by men standing in the troughs. It is spread upon the ground, and when it is sufficiently dried it is dug into the ground by hand. At Bradford it is pumped and flows to a "sludge pond," where it drains and dries. It is sold to the farmers at one shilling per ton. At Leeds, it is given away.

The sludge is disposed of at Burnley by what is known as Gen. Scott's process. By this process the sludge resulting from lime precipitation, which is composed of lime and certain organic matters, is drained, dried by heat, and afterwards burnt in kilns. The residue after burning is ground and forms a very good cement similar to Portland cement. There is usually sufficient lime mixed with the sewage. When the amount present in the sludge is not sufficient, more lime is added during the process of drying. This cement is said to stand a tensile strength of 350 pounds per square inch, after being immersed in water seven days. This refers to pure cement. The cement is sold for thirty-five shillings per ton.

Dr. Wallace* estimated the theoretical manurial value of the sludge from the lime process, by chemical analysis, at from 10*s.* 9*d.* to 21*s.* 7*d.* per ton, the amount of moisture being about twelve per cent.

Chemical precipitation, as at present conducted, fails to remove the whole of the dissolved impurities of sewage. Nevertheless, it is sufficiently purified by chemical precipitation to

* Glasgow Sewage Report, 1879.

meet the requirements of many cases where a high degree of purity is not needed, and a removal of the solids and suspended matters is the main object sought. This, chemistry is able to do, and at the same time prevent the production of the offensive odors that accompany such a separation by gravity alone. Moreover, it is admitted that the chemical processes — some of them at least — remove a portion of the dissolved impurities. The remaining impurities can best be removed by oxidation; either by applying the effluent to the land, where the principles that act for the purification of sewage itself will also act upon and remove the impurities remaining in the effluent from chemical processes; or by discharging the effluent into a stream of pure water, of sufficient volume, the oxygen dissolved in the water being found to gradually remove them. "The results show that, even without contact with the air, the admixture of eight times its bulk of Clyde water is sufficient to effectually oxidize, and so render innocuous, the organic matters in *purified* Glasgow sewage. It need scarcely be added that the crude sewage mixed with Clyde water is not oxidized in the same way."*

So far as we are informed, precipitation works are an annual expense to the municipalities using them for the purification of their sewage. This result is to be expected. The annual cost of the chemicals used forms no inconsiderable item, while the income derived from the sale of sludge for agricultural purposes is uncertain and unreliable. The Native Guano Company and the Rivers' Purification Association each undertake to purify the sewage of cities for fixed annual payments. The last-named association receives, we are informed, about £3,000 per annum for purifying the sewage of Coventry, a city of 45,000 inhabitants, the amount of sewage being about 2,250,000 gallons per day.

Chemical precipitation, although inferior to irrigation in the purification of sewage and in the utilization of its fertilizing properties, may be preferable under certain circumstances, viz.: —

1. When it is impracticable to obtain sufficient land for irrigation.

* Dr. Wallace, Glasgow Sewage Report, 1879.

2. When the land available for irrigation is so far distant from the city as to render the cost of conveying the sewage to it relatively excessive.

3. When the effluent is to flow into the sea, into a tidal estuary, or into a river of large volume below all possible sources of public water supply.

Chemical precipitation and irrigation may be combined with advantage under certain circumstances, viz.: —

1. When the effluent from the precipitation process needs further purification before it is discharged into the streams, as in the case of streams of small volume, or when water is taken from the stream for public water supply, below the point of discharge of the sewage effluent.

2. When the amount of land available for irrigation is limited, less land being required to purify an effluent from precipitation works than is needed to remove the entire amount of impurities from the sewage.

3. When circumstances require that irrigation shall be periodically interrupted; the sewage at such times being purified chemically, either alone or in combination with land irrigation.

COMPARISON OF THE DIFFERENT METHODS OF PURIFYING SEWAGE.

In October, 1879, Dr. R. Angus Smith made an examination of the effluents from several systems of sewage purification, and reported the results of his comparison to the Local Government Board.*

The effluents examined were from: —

1. Aldershot; where irrigation alone is used. Two specimens were collected; one in wet weather, when the purification was less perfect on account of the large amount of sewage, and one in dry weather.

2. Coventry; where precipitation by alum and iron is used first, and irrigation afterwards.

* Rivers' Pollution Prevention Act, 1876. Report to the Local Government Board by Dr. R. Angus Smith, one of the Inspectors under the Act, 1882. [C. — 3080.]

3. Birmingham; where precipitation by lime is used, and the effluent is purified by irrigation. Two specimens were collected, one after lime precipitation and irrigation, and the other after lime alone.

4. Burnley; where the lime process is also used.

5. Aylesbury; where the A. B. C. process is used; the effluent passing directly to the streams from the tanks without filtration.

The report contains extensive tables giving the results of the analyses. The deductions from these tables may be briefly stated as follows: —

"*Free, including Saline Ammonia.* Its existence is of no disadvantage so far as the effect on the atmosphere is concerned, but its absorption by the soil is important as manure. Its amount indicates decomposition. So far as free ammonia is concerned, the first on the list is Aldershot (irrigation) during dry weather. Coventry (precipitation and irrigation) stands second. The next is Aylesbury (A. B. C. process). The lime processes are certainly behind."

"*Albumenoid Ammonia.* Aldershot on a dry day stands best, but not on a wet day. Coventry with its double system is next best. Aylesbury with precipitation alone is almost the same as Coventry with its double purification. Perhaps this expression 'on a dry day' is not quite fair. It is meant to show that in a case of an overflow there may be little or no purification, but there is generally some unless the flood be great."

"*Residual Ammonia.* Aldershot (dry) is again the best; Coventry next; Aylesbury third."

"The two chief ammonias in a sanitary point of view are the albumenoid and residual. They are therefore added."

"*Total Organic Ammonia* (*i. e.*, *Albumenoid and Residual*) *and Total Ammonia.* The lowest effluent for total ammonia (*i. e.*, containing the least) is from the irrigation farm (at Aldershot) in dry weather. Coventry next. Aldershot (wet) and Aylesbury stand third, nearly the same." The lime effluents from Birmingham and Burnley stand last.

"*Nitric Acid.* Nitric acid shows the effect of oxidation on the organic matter, and here the great action of air and of a po-

rous soil shows itself remarkably. The best seems to be irrigation in dry weather, when the land has full opportunity to act."

"The use of precipitation has a decided advantage in wet weather, as it raises the purity of the Coventry water above the Aldershot wet specimen. The precipitation method at Aylesbury (A. B. C. process) is the best of the single processes in wet weather. Aldershot (irrigation) is the best of the single processes in dry. Coventry, the double process, is the best in wet weather. Those which are good in wet weather would probably show still better in dry, if the specimens were taken frequently during the year. The precipitation processes, when alum or iron is used, have an advantage in wet weather, since the act of precipitation becomes an act of disinfection."

"The effluent specimens were examined as to their tendency to putrefy. Those with lime changed most. Aylesbury changed none in a week. Aldershot (dry) may be said not to have changed in twenty-five days."

"The capacity to froth when shaken is a very useful mode of finding the comparative sewage matter rapidly. It may be said to have been absent in Aldershot (dry), Coventry, and Aylesbury effluents. The clearness of the liquid is very important, although a popular indicator. In the Coventry sample there were a few white floating particles. When these fell, the water was clear and colorless. Three specimens, Aldershot (dry), Coventry, and Aylesbury, were without color, when they had stood in a large colorless glass vessel."

"The question has been asked, which of these specimens is most suited for passing into a river. None of these effluents can be called sewer water in the ordinary sense. The Birmingham stream froths readily, and is not pleasant to the eye. The Burnley water was pretty clear, would do well in appearance as a stream by itself, but caused a milky deposit in the river into which it fell, arising, we may suppose, from the free lime taking up some carbonic acid from the river water and precipitating carbonate of lime. The Coventry effluent went into a stream which was very impure; and it might, so far as appearance went, pass into a shallow mountain stream without being noticed. So of Aldershot and Aylesbury."

"In every respect we may say that the best result has been obtained by irrigation when the weather is not so wet as to cause overflowing. Still, it was not found highly successful after lime at Birmingham."

"That the precipitation with alum, or alum and iron compounds, is next."

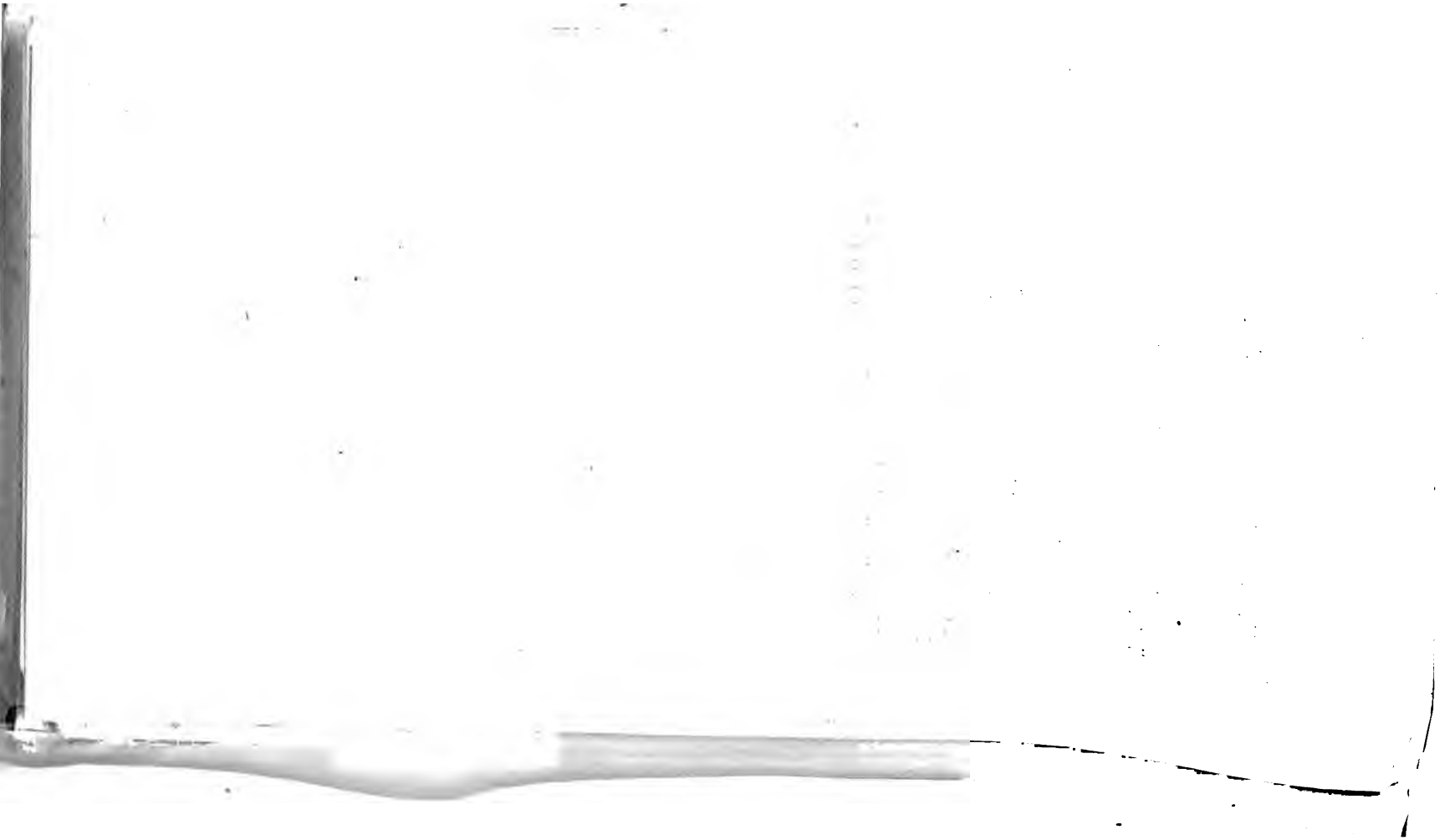
"That in wet weather there is an advantage in precipitation, because the action is largely, if not wholly, independent of dilution."

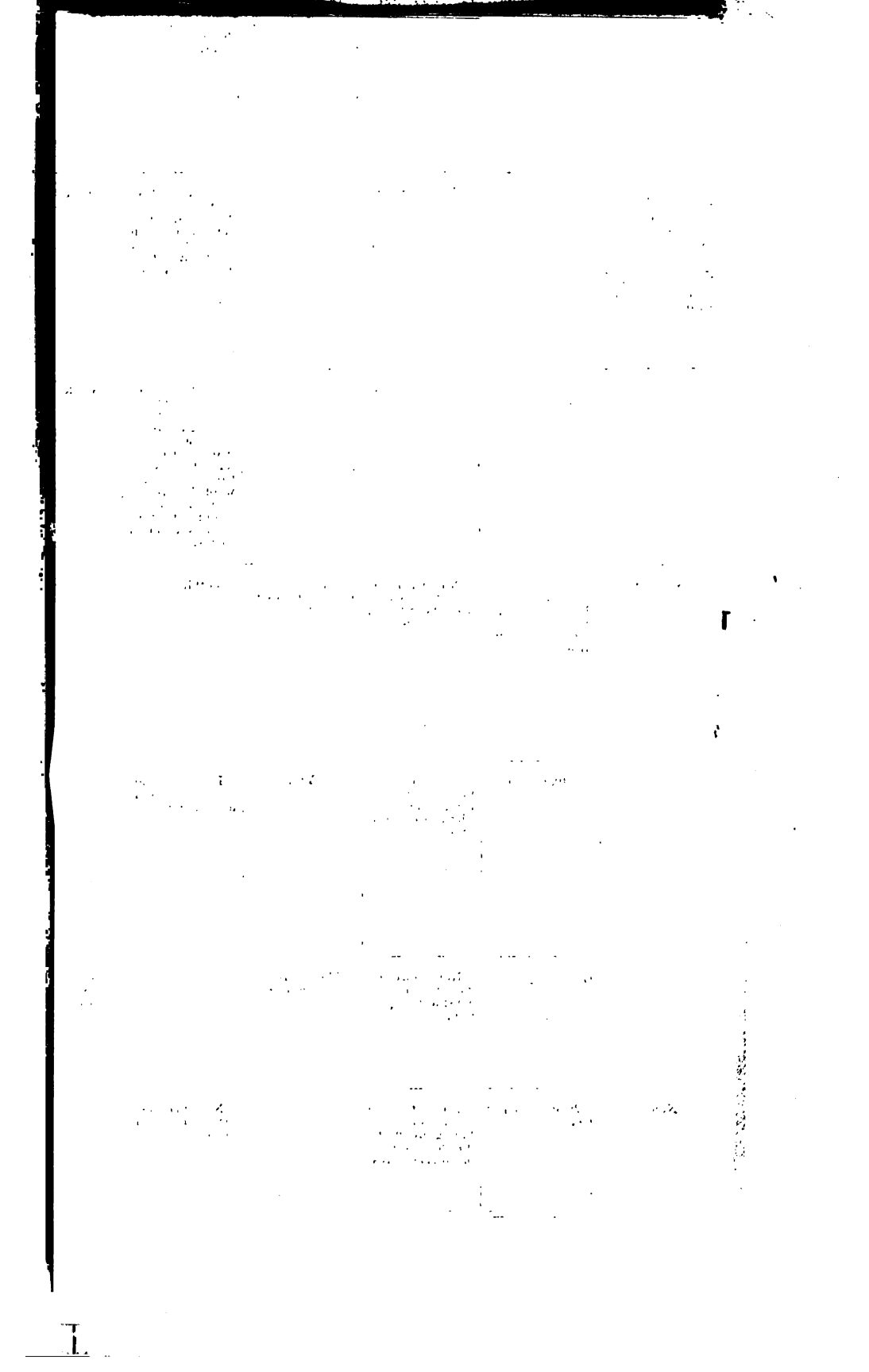
"That the lime process is valuable, but not equal to the above precipitation processes."

"I must repeat that in this report I allude only to the merits of the effluent. There is a good deal to be examined before pronouncing on the ultimate value of the processes."

APPENDIX B.

STATISTICS RELATIVE TO THE TREATMENT AND DISPOSAL OF SEWAGE.





APPENDIX C.

TOPOGRAPHICAL DESCRIPTIONS, LOCATION OF MAIN LINES AND MARGINAL SEWERS, FLOAT EXPERIMENTS, ESTIMATES, LETTERS, PLANS, ETC.

GENERAL TOPOGRAPHY.

By referring to the accompanying map of the city, it will be seen that its surface is divided by means of the Providence, the Woonasquatucket, the Moshassuck, and the West River valleys, together with the Seekonk River as the easterly boundary, into four promontories or topographical divisions, each rising to a considerable elevation, more or less abruptly, from the streams bordering them. For these reasons the surface drainage can be, in most cases, easily effected. The first and flattest section, and the one where the longest lines of drainage are necessary, is the one commonly called the "west side," bounded by the Providence and Woonasquatucket Rivers, and by the depressions formed by Benedict and Mashapaug Ponds. The highest land in this section is about eighty-five feet above mean high tide; quite a large area being between contours seventy and eighty. On the outer edges of this division there are good grades, while the central portion is quite flat, having two depressions in its surface which can be drained only by artificial means.

The second grand division, bounded by the Seekonk River on the east, the harbor on the south, and the Providence and Moshassuck Rivers on the west, rises very abruptly on its westerly side, reaching elevations above mean high tide of one hundred and ninety-five feet on Prospect Hill, near the corner of Prospect and Keene Streets, and of two hundred and two feet on Tin Top Hill, at the corner of East and Doyle Avenues, and having grades averaging from eight to sixteen feet per one hundred feet. The slopes are easier on the east side towards the Seekonk River. The third division, bounded by the Woonasquatucket, Moshassuck, and the West Rivers and the city line, is quite uneven, having elevations as follows: On Smith's Hill of eighty-

five feet, on Mt. Pleasant of one hundred and seventy feet, on Bradley's Hill of one hundred and eighty-seven feet, on the hill just south of Chalkstone Avenue, near Dyerville, of two hundred feet. From this point a dividing ridge runs north to near the city line, at an elevation of one hundred and ninety-six feet. Thence the dividing line runs northerly to Fruit Hill, the highest point of which, near the junction of Fruit Hill and Mineral Spring Avenues, is 287.75 feet above tide water. The fourth division is bounded by the Moshassuck and West Rivers and the city line, and attains an elevation on Windmill Hill of one hundred and eighty-five feet, the highest point on the hill being about at the city line.

The valleys separating these natural divisions are quite low, the first being bounded by tide water from Field's Point to the bridge over the Woonasquatucket River on Valley Street, a distance of 4.7 miles. The second by tide water from the Cove to the city line at Swan Point Cemetery, a distance of 5.2 miles.

The bed of the Moshassuck River at the city line is only about twenty feet above tide. The bed of the West River at the westerly bridge on Branch Avenue, is about thirty feet above tide. The surface of Geneva Pond is about seventy-two feet above tide. The surface of the water of the Woonasquatucket River at Tar Bridge on Manton Avenue in Olneyville is 19.5 feet, and at the bridge at Manton about fifty-four feet above tide water.

It will be seen from this general description of the topography of the city, that while the lines of surface drainage are comparatively short and direct, any sewers designed to intercept the sewage will of necessity be of great length, and will have flat or low grades.

DRAINAGE DISTRICTS.

The surface of the city is divided into a large number of natural drainage areas, varying from a few acres to over 1,250 acres. These areas, with the exception of a few, the drainage from which is intercepted and made to discharge farther down stream, drain directly into the river or into tide water by comparatively short lines of outfall sewers.

To remedy the evil caused by discharging the crude sewage into the streams running through the city, or into tide water, which borders it for so long a distance, it is proposed to build a system of sewers which shall intercept and collect the sewage from the whole city, and convey it to Field's Point.

The four principal divisions of the city are subdivided by the lines of these intercepting sewers into five large intercepting districts, the first comprising that part of the eighth and ninth wards draining southerly and easterly into Cunliff's Pond and Corliss or Old Maid's Cove. The second district is composed of the fourth, fifth, sixth, seventh, and part of the eighth and ninth wards, draining towards the Providence and Woonasquatucket Rivers. The third district is that part of the tenth ward draining towards the Woonasquatucket River. The fourth district includes all that part of the tenth, first, second, and third wards draining into the Moshassuck, West, and Providence Rivers. The fifth district contains that part of the tenth, first, second, and third wards draining towards the Seekonk River and into the harbor.

These five principal intercepting districts are shown on separate contour maps, covering together the entire area of the city, and showing the districts divided into the natural subdivisions, with the lines of main intercepting, main district and lateral sewers.

It is believed that the territory near Field's Point furnishes the proper and natural place for the concentration of the sewage of the city. It is nearly at its southern extremity and below the point where the drainage of the ninth ward is brought to tide water. It is also in proximity to the most favorable point for the discharge of the effluent. Here the narrowness of the channel, through which the tidal contents of the harbor and river above flow at every ebb tide, creates a strong and swift current. It is probably the best place in the near vicinity of the city for this purpose.

The location of the pumping station is shown at A, on plan of the ninth ward, near Allen's Avenue, on the south side of Corliss Cove. The precipitation tanks, together with small buildings necessary, are shown as occupying the low ground at

point B. The outfall sewer is shown as running to deep water opposite the Point.

DESCRIPTION OF INTERCEPTING SEWERS.

From the pumping station the lines of main intercepting sewers, one for the ninth ward, and the other for the remainder of the city, will run westerly till they reach Allen's Avenue. From this point the ninth-ward sewer runs westerly along the southerly side of Corliss Cove, crossing Eddy Street some four hundred feet south of the old Stonington Railroad Bridge; thence to the junction of Plane Street with the said railroad; thence southwesterly by the side of the railroad location to the corner of Roger Williams Avenue and Hamilton Street; thence through Roger Williams Avenue, Cobden Street, and Bartlett Street to the west side of the New York, Providence, and Boston Railroad; thence following along the westerly side of the railroad to Crocker Avenue; thence through Crocker Avenue and by Long Pond to the corner of Dexter and Cromwell Streets. This sewer intercepts the drainage of the district bounded on the east by Eddy Street, from the city line to O'Connell Street; on the north and east by Pearl Street district to the corner of Division and Bridgham Streets; on the west by Benedict Pond district, from Willow Street to Cranston Street, and by Fenner's Avenue and Mashapaug Pond, and extending from Dexter Street on the north to the Cranston line on the south, containing about 1,550 acres. This includes the area of Long Pond and Roger Williams Park, but does not include any of Mashapaug Pond.

Of this amount about four hundred and sixty acres drain into Long and Mashapaug Ponds, about seven hundred and eleven acres into Cunliff's Pond, and the balance, or three hundred and forty-four acres, into Corliss Cove.

The intercepting sewer for the ninth ward will discharge by gravity into the precipitation tanks.

From the point where the ninth-ward sewer leaves Allen's Avenue, the main intercepting sewer will run northerly, intercepting the sewage from the territory east of Eddy Street and

between Corliss Cove and Blackstone Street, containing about one hundred and forty acres. At Blackstone Street the line crosses the Pearl Street district outlet. At Langley Street the line divides, one part turning to the right, passes down Langley Street and crosses the Providence River, by a siphon, to the foot of India Street. This line takes the Seekonk, and the Moshassuck and West River districts. The other part runs northerly into and through Eddy Street to Ship Street, crossing the outlets of the Point Street district, and at Elm Street crossing the Elm Street intercepting sewer.

This sewer, commencing on Atwell's Avenue at Bourne Street, running through Bourne Street, Broadway, Jackson, High, Chestnut, and Elm Streets, intercepts the sewage from an area of two hundred and sixty-two acres, which would naturally flow down to the low, flat part of the city near Dorrance Street. By this sewer the Dorrance Street district is relieved from the sewage coming from about sixty-two per cent of its original area.

From the main intercepting sewer at the junction of Ship and Eddy Streets, a branch will run up Dyer Street to Westminster Street, taking the sewage from the Dorrance Street sewer, from the outlet on Dyer Street, of Pine, Custom House and Dyer Street sewers, and from the sewer in Westminster Street, which now has its outlet under the Great Bridge.

The main sewer will run through Ship, Richmond, and Mathewson Streets to Cove Street. Here dividing, one line crosses the Cove lands about on the line of Park Street, and runs up the valley on the north side of the Woonasquatucket River. The other line keeps on the south side of the river, running through Cove Street to Harris Avenue, and takes the sewage from the West Exchange Street sewer, which is also an intercepting sewer, receiving the sewage from an area of one hundred and sixty-four acres, bounded on the north and west by West Exchange, Ridge, and Tobey Streets, and extending as far south as Willow Street.

From the corner of Cove Street and Harris Avenue, the main continues through Harris Avenue to Grove Street, thence through Grove Street to Valley Street, and through Valley Street to Broadway.

At a point about four hundred feet north of Broadway, the main intercepting sewer again divides, one branch crossing under the river just above the Valley Bleachery dam, continues through to Manton Avenue, thence through Manton Avenue and the yard of the Atlantic Mills to Aleppo Street, thence through Aleppo Street and following the right bank of the river and along the Springfield railroad location nearly to Dyerville, there keeping on the east and north sides of the Dyerville Pond to Manton Avenue Bridge at Manton.

Future local changes may require some modifications in the position of the line from Aleppo Street. Its construction will probably be long deferred.

The other branch of the main, running in Valley Street, crosses Broadway and High Street and runs to Oak Street, thence through Oak Street to Norfolk Street, where it receives the sewage from the sewer draining the Benedict Pond drainage district.

The drainage from considerable areas of land lying outside of the present city limits in Johnston concentrates on Valley Street at High Street and Oak Street. This district, in view of its rapidly increasing population, of its close proximity to the city, and of the probability that it will become a part of the city at no distant day, has been provided for in designing the sewerage system.

The area from Johnston naturally draining towards the places indicated is about four hundred and twenty-eight acres, and embraces the territory lying east of a line running from the top of Rocky Hill to the Merino Mills. An area on the east slope of Rocky Hill, of one hundred and ten acres in the town of Cranston, also drains towards Benedict Pond; the larger part of which should be considered as belonging to that district. The district lying without the city is represented on the map showing the fourth, fifth, sixth, seventh, and eighth wards. The branch leaving the main sewer at Cove and Mathewson Streets, after crossing the Cove lands and passing under the Woonasquatucket River, runs westerly in Promenade Street to a street parallel with and about two hundred feet east of Hemlock Street, thence through said street to Valley Street, then westerly

through Valley Street to Atwell's Avenue. This sewer will be low enough to drain all the large manufacturing establishments on or near its line.

A large and as yet unplatted area, lying between Smith Street and Chalkstone Avenue, and west of River Avenue, containing about eight hundred and fifty acres, has for its natural outlet the brook through what is called Pleasant Valley, and a main sewer is shown following the general line of the brook, from Valley Street to River Avenue, in a street that should be laid out for this purpose. To the east of this district and bounded by Ruggles Street, Douglas Avenue, Pekin Street, Chalkstone Avenue, and Smith Street, is an area of about 26.5 acres commonly known as the Hardenburg District, from which no outlet exists for the surface water or sewage.

The difference of elevation between the surface of the surrounding streets and that of the lower part of this area has made it a matter of considerable study to determine the best method of providing for its drainage. By following the line as shown on the map in Chalkstone Avenue and Mason Street, crossing Smith Street and Ruggles Street to Danforth Street, a sewer can be easily built that shall effectually provide for the lowest probable grade in the district, which is about twenty feet below the lowest established grade in the surrounding streets.

That branch or part of the main intercepting sewer which passes under the Providence River, by a siphon, divides at the corner of South Water and India Streets; the Moshassuck River branch turning to the left into South Water Street, the Seekonk River branch keeping on and through India Street to Gano Street, thence through Gano Street to William Street, there turning to the right and crossing the flats parallel with the harbor line to Pitman Street; then crossing Pitman Street and running through East River Street and crossing Waterman Street the line follows the shore line of the Seekonk River into Blackstone Avenue; thence in Blackstone Avenue to the outlet of the Butler Hospital Brook; there following the brook to the point reached by mean high tide. The area above this point and which drains through the brook is 463.53 acres. This amount does not include eighty-eight acres in Swan Point Cem-

etery, and forty-six and one half acres in Butler Hospital grounds, which drain into the Seekonk River. The latter areas will probably never need a sewer.

The Seekonk River branch is shown on the map showing those parts of the first, second, third, and tenth wards draining into the Seekonk River. The Moshassuck and West River branch, starting from India Street, follows the line of South Water and Canal Streets to Smith Street, intercepting the sewers emptying into the Providence River, the first on the west side of the line being at Smith Street; thence in the line of Canal Street and following along the bank of the Moshassuck river to Mill Street; thence through Bark Street to a point just above the Snow and Lewis dam, where the line turns and crosses under the river and into Charles Street, a short distance south of Orms Street; thence through Charles Street to Randall Square. At this point the line divides, one part turning to the west through Martin Street and following up the West River valley, the other following the Moshassuck River valley. The latter line will leave Charles Street, and turning to the right pass through the yard of the Franklin Foundry to their dam; thence passing under the river and turning to the right into Printery Street at Nash Lane; thence in Printery Street to near Livingston Street, there turning to the left, crossing the yard of the Allen Print Works and keeping close to the east bank of the old canal to near Branch Avenue; then passing under the river and keeping on the left or westerly side of the river to Smithfield Avenue; thence parallel to the old canal to Cemetery Street; thence following the bed of the old canal to the city line.

An area of about forty-five acres just west of Smithfield Avenue naturally drains to the low ground west of the railroad between Smithfield Avenue and Cemetery Street. The only outlet of this area is over the surface across Cemetery Street into Clarke Street, and through the grounds of the abattoirs under the railroad and into the swamp. This line is the best one to follow in sewering this area, although it involves the carrying of sewers outside the city and through a part of Pawtucket. It is proposed, therefore, to open a new street from a low point in Smithfield Avenue to a low point in Cemetery Street at Clarke Street.

From the railroad to the old canal this line follows a platted street.

With the sewer passing directly through the abattoir grounds, all the sewage can be collected from the same, thereby relieving the Moshassuck River from objectionable matter that has caused much complaint.

That part of the Moshassuck River Valley lying within the limits of the town of Pawtucket, estimated to be 1,417 acres, has no means of outlet except through the city of Providence. Parts of this area are destined to be very thickly settled, in fact are already being built upon, and the question of the disposal of its sewage has been considered in connection with the areas lying within the city limits, in the determination of the sizes of main sewers, sewerage works, etc. The line of main sewer is therefore shown as crossing the city line.

At Cemetery Street an area of about one hundred and eighty-two acres lying between North Street, East Avenue, and the city line is brought to the main. An area of about 124.8 acres comes in at Smithfield Avenue, mostly through Northup Avenue. The area bounded by the railroad and Branch Avenue, the river, Burt Street, and Cross Street will have to be taken under the river near Deer Street. An area of 115.7 acres, bounded by Earle's Lane, Pleasant Street, East Avenue, North Street, and North Main Street, joins the main at Livingston Street.

The sewage from Whelden Street, Nash Lane on the west, Randall, Stevens, and a part of Charles and Smith Streets, will have to be taken under the river to the main.

The West River branch of the main will run through Martin and Ashburton Streets, crossing the railroad and turning when in line with Charles Street; thence through Charles Street to a point just beyond Leonard's Pond, at an angle in Charles Street; thence following the north side of the pond straight to Branch Avenue at the easterly bridge; thence in Branch Avenue to Douglas Avenue; thence by a new street westerly to Admiral Street.

The upper end of the drainage area is a little south of where Smith Street crosses the city line, between Admiral Street and

that point, covering an area of about one hundred acres, there is no proposed lay-out, but by a proper treatment nearly all the drainage can be kept within the city limits.

At Veazie Street the sewage from eighty-four acres will be brought under the river to the main line. The main will pass under the river at both bridges on Branch Avenue near Wanskuck, and also at the bridge on Charles Street. It is proposed to open a street from the end of Langdon Street to the proposed street for the main sewer, to facilitate the alignments. Drainage from an area of about seventy-four acres will come to the main at Hawkins Street. Drainage from an area of about 98.6 acres is brought to the main sewer through Admiral Street; also near Webster Street drainage from an area of about 197.8 acres is received coming through Oregon Street.

From the junction of Webster Street and the railroad track to the corner of Oregon and Borva Streets, a new street is shown, giving an outlet for the drainage coming through Oregon Street. Future local changes may require a considerable modification of the lay-out in this vicinity.

In the compilation of the maps showing the above-described lines, a large amount of original information has been used for the first time. Some six hundred trigonometrical points, covering the larger part of the city, obtained during the last seven years by the street line department of this office, from actual surveys and from calculations made from existing plats, have been used as a foundation, and the filling in has been from surveys made by the sewer department, from recorded plats and from the assessor's plats. The base from which the trigonometrical points have been calculated is a north and south line running through old Fort Independence, the latitude and longitude of which was obtained by the United States Coast Survey. This point has been used as zero. Short lines with figures on the sides of the maps represent the number of parallels of 800 meters, or 2625.56 feet, each, starting from the zero point.

The contours on these maps represent continuous elevations or planes above mean high water, and are ten feet apart vertically; they have been obtained for the larger part of the city by the sewer department within the last eight years.

FLOAT EXPERIMENTS.

In order to be able to intelligently judge of the probable effects that would be produced if crude sewage should be habitually emptied into the Providence River or Narragansett Bay, a series of float experiments were carefully made to obtain information relative to the tidal flow. Plate XXII. illustrates the form of floats used.

The floats were made of clear white pine, four inches in diameter, well oiled and shellacked, and of several lengths as shown, weighted at the lower ends with lead cast of the same diameter as the float, and heavy enough to sink the float even with the water surface. These floats carried a small vertical wire, as represented in the plate, two feet or more in height, on top of which was a light wooden ball painted with luminous paint; a small lantern was suspended on this wire in the night time.

The experiments extended over a period of several months, during which time floats were started from a point off Field's Point, from a point in the channel opposite Bulkhead Rock, and from a point about three hundred feet below Conimicut Point lighthouse.

These floats were followed by parties in boats night and day, Sundays excepted, who located, by means of compass courses, the position of the float every half-hour, or oftener, as it seemed necessary, and recorded the same on blanks and charts prepared for the purpose, keeping also a record of the direction of the wind, its relative force, and the state of the weather. Some of these charts have been reduced, and are to be found in Appendix C, on which are shown several representative experiments. Plate XVII. shows the track of six floats started at Field's Point, among them that of the float making the longest run of any. Plate XVIII. shows the track of three floats started at Conimicut Point. The reference table gives the time of starting and of grounding, time of high and low tide, etc. Plate XIX. shows an experiment made with planing-mill chips, to ascertain the extent of water surface that would be covered by any light floating bodies set loose at Field's Point,

as well as that part of the shore line that would be affected thereby. For this purpose, several barrels of hard-pine shavings or planing-mill chips were thrown overboard just off the point, and as they spread out and floated away, the edges of the flow were carefully located; as the tide turned they began to ground near Sabine's Point, and were found all along the shore as far north as Cranberry Island, where the last chips were found about six o'clock P. M.

Plate XX. gives the track of all floats started from Field's Point, or opposite Bulkhead Rock. On Plate XXI. is given the points where the various floats grounded, also the location of the leased oyster beds for the year 1883, as obtained from the maps in the office of the Commissioners of Shell Fisheries. The reference table explains the chart.

The maps and plans contained in this report were printed by the Photo-Electrotype & Engraving Co., A. P. Mathewson, of Providence, R. I., agent.

TABLE GIVING RESULTS OF FLOAT EXPERIMENTS MADE IN THE FALL OF 1883.

FLOATS STARTED FROM FIELD'S POINT.

No. of floats that grounded in each tide.	Per cent of whole number started.	Distance between points of starting and grounding.			Speed per hour.		No. of floats having fair winds.	Speed per hour.		No. of floats having side winds.	Speed per hour.		No. of floats having head winds.	Speed per hour.		Remarks.
		Longest.	Average.	Shortest.	Greatest.	Average of Maximums.		Greatest.	Average of Maximums.		Greatest.	Average of Maximums.		Greatest.	Average of Maximums.	
31 in 1st tide.	69 %	5¾ m.	1.41 m.	-0.75 m.	1.0 m.	0.644 m.	17	1.3 m.	0.716 m.	6	0.75 m.	0.633 m.	8	0.50 m.	0.50 m.	
11 " 2d "	24 "	4¾ "	2.0 "	-0.87 "	1.0 "	0.609 "	9	1.33 "	0.727 "	1*	0.25 "	0.25 "	1	0.87 "	0.87 "	[flats.* Long float dragged on
1 " 3d "	2½ "	7⅞ "	7.87 "	7.87 "	0.50 "	0.50 "	1	0.6 "	0.60 "							
1 " 4th "	2½ "				0.60 "	0.60 "	1	0.5 "	0 50 "							
1 " 5th "	2½ "				1.333 "	1.333 "	1	1.333 "	1.333 "							
FLOATS STARTED OFF BULKHEAD ROCK.																
5 in 1st tide.	83 %	2½ m.	1.35 m.	0.63 m.	0.75 m.	0.54 m.	2	0.75 m.	0.635 m.	3	0.67 m.	0.48 m.				
1 " 2d "	17 "	2¾ "	2.75 "	2.75 "	0.47 "	0.47 "				1	0.47 "	0.47 "				
FLOATS STARTED FROM CONIMICUT POINT.																
4 in 1st tide.	33 %	3½ m.	2.69 m.	2.25 m.	0.70 m.	0.61 m.	3	0.65 m.	0.61 m.	1	0.60 m.	0 60 m.				
6 " 2d "	50 "	6½ "	1.17 "	-0.38 "	0.60 "	0.465 "				2	0.58 "	0.50 "	4	0.60 m.	0.45 m.	
2 " 4th "	17 "	-0.87 "	0.94 "	1.00 "	0.45 "	0.44 "	1	0.45 "	0.45 "				1	0.40 "	0.43 "	

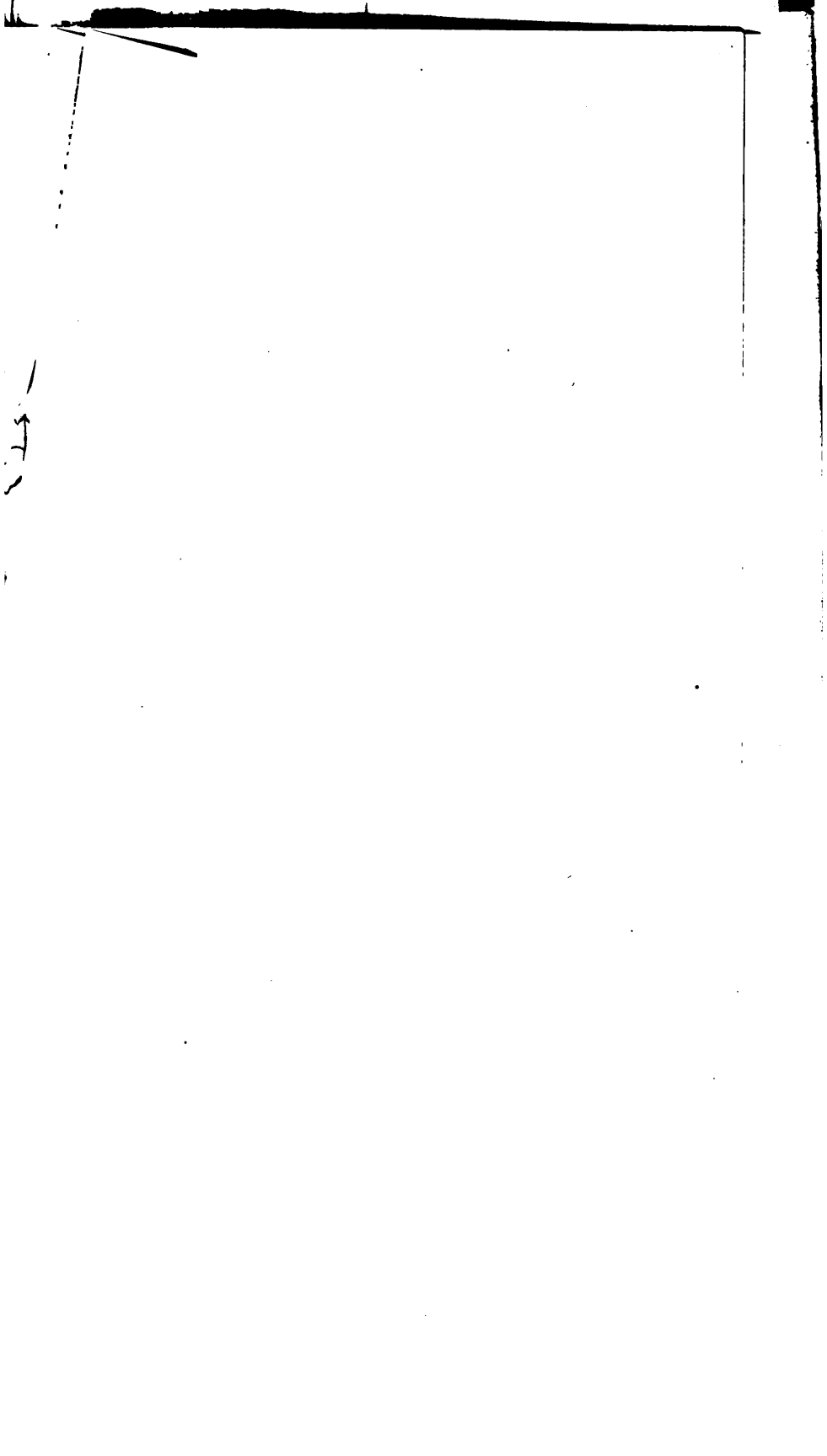


TABLE GIVING RESULTS OF WEIR MEASUREMENTS TAKEN IN THE OUTFALL SEWERS MENTIONED.

District or Sewer.	Total present Population.	People per House.	Houses Connected.	Population Connected.	Time when Flow is above or below line of average Flow.				Discharge while above or below line of average Flow.				Gallons per head of Population Connected.			Total Meas. Discharge per Day.	Average Discharge per Second.	Maximum Discharge per Second.	Reference to Date of Measurements.
					Above.	Hrs.	Below.	Hrs.	Above.	%	Below.	%	Per Day.	While above average line.	While below average line.				
Dorrance St.		8.5	772	6,562	7.42 to 7.0	11.18	7.0 to 7.42	12.42	412'089	65	220'744.	35	96.44	62.79	33.64	632'833.	7.32	11.65	Average, May and June.
Brook "	6,178	7.88	575	4,480	6.48 " 5.12	10 24	5 12 " 6.48	13.36	226'410.	44	284'504.	56	114.05	50.50	60.50	510'944.	5 92	6.78	Saturday, Feb. 2, 1884.
" "		"	"	"	6.30 " 3.06	8.36	3.06 " 6.30	15.24	200'434.	41	284'570.	59	108.28	44.74	63.54	485'107	5.61	"	Monday, Feb. 4, "
" "		"	"	"	7 00 " 7.30	12 30	7.30 " 7.00	11.30	200'862.	58	144'612.	42	77.03	44.84	32.19	345'474.	3.985	5.47	Tuesday, July 1, "
" "		"	"	"	6.45 " 6.05	11.20	6.05 " 6.45	12 40	187'924.	56	147'530.	44	74.83	41.72	33.11	335'354	3.88	5.47	Thursday, " 3, "
" "		"	"	"	6.26 " 8.15	12 15		11.45	193'464.	58	140'148.	42	74.47	43 19	31.28	333'612.	3.86	5.76	Saturday, " 5, "
" "		"	"	"	6.45 " 4.15	9.30	4.15 " 6.45	14.30	161'624.	44	208'096.	56	82.53	36.08	46.45	369'720	4.28	5.47	Monday, " 7, "
Elm "	12,536	7.9	1,114	8,800	7.15 " 5.15	10.00	5.15 " 7.15	14.00	208'.05.	58	150'200.	42	40.76	23.69	17.07	358'705.	4.15	7 90	Monday, Jan. 28, "
" "		"	"	"	7.0 " 5.30	10.30	5.30 " 7.0	13.30	188'406.	59	130'726.	41	36 27	21.41	14 86	319'132.	3.69	7.90	Tuesday, " 29, "
" "		"	"	"	6.50 " 6.45	11.55	6.45 " 6.50	12.05	194'274.	68	92'358.	32	32.57	22.08	10 49	286'632.	3.317	6 32	Wednesday, June 4, "
" "		"	"	"	7.03 " 7.28	11.34		12 26	202'266.	69	88'828.	31	33.08	22.99	10.09	291'094.	3.37	6.32	Friday, " 6, "
" "		"	"	"	6.13 " 8.11	13.58	8.11 " 6.13	10.02	199'188	74	68'328	26	30.40	22.63	7.77	267'516.	3.10	5.11	Thursday, " 19, "
No. Main "	2,316	8.5	172	1,462	6.51 " 4.42	9.51	4.42 " 6.51	14.09	130'818.	59	90'850.	41	152.2	89.47	62.73	222'668.	2.57	4.45	Monday, May 12, "
" "		"	"	"	6.50 " 5.20	10.30	5.20 " 6.50	13.30	116'304.	54	96'432.	46	145.5	79.55	65.95	212'736.	2.46	3.80	Wednesday, " 7, "
" "		"	"	"	4 58 " 6.36	12.02		11.58	104'969.	69	47'481.	31	104.28	71.80	32.48	152'450.	1.76	3.25	Friday, July 25, "
Blackstone "	12,529	7.8	606	4,727	6 00 " 5.30	11.30	5.30 " 6.0	12.30	83'628.	64	46'312.	36	27.49	17.69	9.80	129'940.	1.50	3.20	Monday, Feb. 11, "
" "		"	"	"	6.30 " 4.26	9 56	4.26 " 6.30	14.04	155'214	73	56'394.	27	44.76	32.83	11 93	211'608.	2 40	5.40	Thursday, " 14, "
" "		"	"	"	6 30 " 4 26	"	4.26 " 6.30	14.04	151'170.	73	56'340.	27	43.89	31.98	11.91	207'510.	2.30	4 82	Saturday, " 16, "
" "		"	"	"	7.30 " 4.45	9.15	4 45 " 7.30	14.45	79'977.	44	98'367.	56	37.73	16 94	20.79	178 344.	2.06	2.65	Monday, " 18, "
" "		"	"	"	7.00 " 5.0	10 0	5.0 " 7.00	14.00	97'262	53	84'780.	47	38.51	20 57	17.94	182'042.	2 106	3.20	Friday, " 29, "
Pitman "	859	7.7	86	656	8.30 " 4.45	8 15	4.45 " 8.30	15.45	48'206.	46	55'602.	54	158 6	73.72	84 87	1 3'898	1.202	2.38	Monday, April 28, "
" "		"	"	"	5 45 " 3.45	10.00	3.45 " 5 45	14 00	31'135.	46	33'206.	54	98.23	47.53	50.70	64'341	.744	1.38	Wednesday, " 30, "
Ives "	3,397	8.89	204	1,814	6.36 " 4.45	10.09	4.45 " 6.36	13.51	34'199.	52	30'817.	48	35.84	18.85	16 98	65'016.	.7.3	1.02	Monday, March 3, "
" "		"	"	"	7.00 " 4.45	9.45	4.45 " 7.0	14.15	38'371.	52	35'473.	48	40.70	21.15	19.55	73'844	.854	1.36	Wednesday, " 5, "
" "		"	"	"	7.45 " 7.45	10.12		13.48	33'318.	55	22'778.	45	33.12	18.36	14.76	60'096.	.695	1.30	Monday, Aug. 25, "

Ives	St.		"	"		6.45 to 8.20	13.39			10.21	33'441.	64	18 420.	36	28.58	18.43	10.15	51'861.	.60	0.92	Wednesday, Aug. 27, 1884.
College	"	1,164	7.7	108	824	6.45 " 9.00	13.15	7.0 to 6 45		10.45	59'409	65	31'983.	35	110.91	72.09	38.82	91'392.	1.05	1.82	Friday, May 2, "
"	"		"	"	"	7 0 " 11.	11.0	5.0 " 7.0		13.00	51'912.	56	40'248.	44	111.84	63.00	48.83	92'162.	1.07	1 81	Monday, " 5, "
Point	"	3,738	8.5	321	2,729	10. " 5.00	13.45	8.30 " 6.45		10.15	94'788.	69	41'004.	31	49.75	34.73	15.02	13'792.	1.57	3 82	Mean line, May. 6-21 "
Power	"	265	7.7	31	239	6.0 " 8.15	14.15	8.15 " 6.0		9.4	16'073.	72	6'122.	28	92.86	67.25	25.61	22'195.	0.26	.56	Wednesd'y, Apr. 23, "
"	"		"	"	"	6.0 " 8.30	14.30	8.30 " 6.0		9.30	16'138	73	5'906.	27	92.23	67.52	24.71	22'044.	0.26	.54	Friday, " 25, "
"	"					6.40 " 8.30	12.24			11.36	3'174.	80	788.	20	16.16	13.28	2 88	3'902.	0.045	.14	Friday, Aug. 22, "
Nash	Lane,	394	7.7	25	193	5.30 " 8.00	11.20			12.40	2'066.	63	1'214.	37	17.00	10.70	6.29	3'280.	.037	.135	Monday, April 21, "
"	"		"	"	"	" " "	11.06			12.54	1'580.	60	1'056.	40	13.66	8.20	5.46	2'636.	.030	.06	Tuesday, " 22, "
"	"					" " "	12.39			11.21	2'423.	76	736.	24	16.36	12 55	3.81	3 159.	.036	.086	Wed'y, Aug. 6, 7, 11, "
Park	St.	276	7.7	21	162	7.15 " 8.45	10.24			13.36	1'950.	65	1'027.	35	18.37	12.04	6.33	2'977.	.034	.187	Friday, April 18, "
"	"		"	"	"	7.0 " 8.30	7.10			16.50	3'102.	83	606.	17	22 88	19.14	3.74	3'708.	.043	.385	Monday, Aug. 18, "
Martin	"	1,801	7.7	153	1,178	8.0 " 9.30	13.30	9.30 " 8.0		11.30	68'760.	66	35 615.	34	88 60	58.37	30.23	104'375.	1.208	1.40	Wednesday, July 9, "
"	"		"	"	"	6.45 "10.45	16.0	10.45" 6.45		8 00	58'129.	70	24'758	30	70.36	49.34	21.01	82'887.	0.959	1.20	Friday, " 11, "
"	"		"	"	"	7 0 " 7.45	12 45	7.45 " 7.0		11.15	46'368.	68	21'440.	32	57.56	39.36	18.20	67'806.	0.783	1.40	Monday, " 14, "
"	"		"	"	"	7.6 " 8.0	12.54	8.0 " 7.06		11.06	40'072.	64	22'941	36	53.49	34 01	19.47	63'013.	0 729	1.10	" " 21, "
Stevens	"	1,773	7.7	95	732		15.15			8.45	155'387	70	85'300.	30	301.61	212.28	89 33	20'777.	2.558	3.46	Thursday, " 17, "
"	"		"	"	"		5.26			18.34	51'849.	23	170'624.	77	308.92	70.83	238 09	222'473.	2 575	3.35	Monday, " 21, "
Whelden	"	527	7.7	27	208	5.50 " 7.50	12.50			11.10	2'961	76	931.	24	18.71	14.24	4 47	3'892.	0.043	0.097	Friday, Aug. 15, "
"	"		"	"	"	5.30 " 8.24	12.0			12.00	3'730.	72	1'461.	28	24.91	17.93	6.98	5'191.	0.060	0.187	Tuesday, " 12, "

POPULATION, NUMBER OF HOUSE CONNECTIONS, AND HOUSES CONNECTED, JUNE 1, 1884.

District.	Present Population Connected.	Number of House Connections.	Number of Houses Connected.
Pearl Street	4,727	454	606
Point "	2,729	206	321
Elm "	8,800	852	1,114
Dorrance Street	6,562	635	772
Weybosset and Westminster Streets	316	39	41
Holden Street	54	5	7
Park "	162	11	21
Orms and Charles Streets	123	13	16
Martin Street	1,178	122	153
Nash Lane	193	22	25
Whelden Street	216	20	28
Livingston Street	454	42	60
Stevens "	732	71	96
Lane, opposite Star Street	31	4	4
Amos Street	54	7	7
North Main Street	1,462	156	172
College "	824	91	106
Crawford "	100	12	13
Power "	239	27	31
Pike "	285	22	37
Brook "	4,480	456	575
Ives "	1,514	166	204
India "	231	23	30
Pitman "	655	72	86
Totals	36,421	3,523	4,526

ESTIMATE.

For all main and intercepting sewers, as described in Appendix C, pages 126–132, including all necessary man-holes, flush-gates, regulating chambers, tide-gates, etc. . .	$2,195,973	00
For pumping station, including engine and boiler house, pump well, filth hoists, and steam machinery capable of pumping at the rate of 58,000,000 gallons per twenty-four hours	275,133	00
Precipitation tanks and connections . . .	95,300	00
Conduit between pumping station and precipitation tanks	63,428	00
Filter press and machinery for mixing chemicals, with buildings, storehouse, etc. . . .	50,000	00
Outfall sewer from precipitation tanks to tide water	75,142	00
Houses for engineers, superintendent, etc. .	10,500	00
Earth excavations, grading, etc. . . .	50,000	00
Wharf, railroad connections, etc. . . .	35,000	00
Land, rights of way, land damages, etc. . .	366,484	00
	$3,216,960	00
Add 15 per cent for engineering and contingencies	482,544	00
Total	$3,699,504	00

CORRESPONDENCE.

LETTER FROM JOHN HOWARD APPLETON,

Professor of Chemistry in Brown University.

PROVIDENCE, Sept. 30, 1884.

SAMUEL M. GRAY, Esq., *City Engineer, etc.*

Dear Sir, — In reply to your inquiry, I take this means of presenting my views upon the general question of the disposal of the sewage of the city of Providence.

It seems to me that a comparatively brief examination of the subject ought to lead to the conclusion that the introduction of crude sewage into the waters of Providence River is highly undesirable.

It cannot be denied that there has grown up in many parts of the world the practice of casting sewage into the nearest water-course. This disposition of waste matter has been widely adopted as the most simple one by manufacturing establishments and towns, as well as by individuals dwelling on the banks of convenient streams. But I believe that most thinking people will acknowledge that the habit is a slovenly one, and that whether practised on a large or on a small scale it ought to be discontinued, if possible. The mere fact that otherwise pure and attractive streams are rendered offensive to the eye and blots on the landscape ought, it would seeem, to be sufficient to lead to a discontinuance of the pollution. Certainly a great city ought not to heedlessly pollute its chief water-courses, which otherwise would be open highways of pure water and sweet air for the refreshing of its entire population.

True, in cases like our own such proceedings have sometimes been tolerated in their earlier stages; but I believe that a time comes when if they are persisted in, the results become unendurable.

Probably, when many years ago impurities first made their way into our Cove basin it seemed unlikely that they would ever reach it in sufficient amount to be an annoyance. To-day, however, the nuisance caused by permitting this pollution has become so considerable as to give rise to the universal condemnation of it, and to a widespread feeling that it must be somehow abated, even though a large expense is thereby incurred.

The most natural and simple device for relieving the Cove and harbor involves the construction of marginal sewers to intercept the sewage now entering these waters and to empty it crude into the river at a point slightly more distant from the centre of the city, — say just below Field's Point.

It seems to me that if this method were followed it would produce in that portion of the river between Field's Point and Pawtuxet Neck a sort of imitation of the present Cove basin; of course the copy would be on a somewhat larger scale, and perhaps for a few years it would be somewhat less offensive, than its prototype. It seems likely, from the experimental evidence at my disposal, that the ultimate result must be an objectionable condition of the water of the area outlined, and indeed perhaps of a still larger tract of river than that mentioned.

I am not able to predict very definitely and in detail the results of an adoption and carrying out of the plan just touched upon, but I will offer the following general statements.

If the entire sewage of the city of Providence were allowed, in a crude state, to enter the river just below Field's Point, I think that there would result, first, an offensive discoloration of these waters. Next, the gradual progress of the lighter portions of the impurities would extend the discolorations somewhat farther down the bay. Such action on the part of the city of Providence would undoubtedly create at once a prejudice against estates bordering on the waters of this portion of the river, and so would do a direct injury to the owners of these estates. The mere apprehension that the city may pursue the course just outlined is to-day working some injury to real estate on the banks of the bay just below the city. The realization of these plans would be still more injurious.

Further, I believe that some portion, at least, of the filth of the sewage would deposit itself in an ever-increasing layer upon the bottom of those parts of the river reached by it. The extent of such a deposit would undoubtedly be wide. Owing to its greasy and otherwise offensive character, it must be anticipated that the oysters and other valuable inhabitants of our waters could not continue to flourish in its presence. If this view is tenable, such result would be disastrous to the interests of the large class of persons having business depending on our local fisheries.

Again such solid impurities in the crude sewage as do not quickly deposit in the way described, would continue on their various courses. The lighter of them would tend to gather in still places on the shores, rocks, and beaches of the river, while others would necessarily find a resting-place a little farther down the bay.

In any case, the organic matters of the sewage would be likely to undergo some decomposition, as a result of which sulphuretted hydrogen and other offensive gases would be produced. If such gases should be formed in considerable quantity and wafted to the residences along the shores of the bay, they would tend to produce that depressing and unwholesome feeling noticeable in cities where bad smells abound; yet more, delayed convalescence and positive disease would probably be numbered among the more marked effects.

If the results here pointed out should be produced in fact by the action of the city in this matter, they must be followed by bitter condemnation of its course, and I think by ultimate reformation of the system. In this light it would seem to be the dictate not only of wisdom but of common prudence to make arrangements, at the outset, for such inoffensive disposal of our sewage by chemical precipitation, by irrigation, or by a combination of these, or by other processes which our circumstances make practicable. Thus we should avoid deliberately producing nuisances, which the ultimate and just clamors of the sufferers from them would force us by and by to remedy.

Yours respectfully,

JOHN HOWARD APPLETON.

LETTER FROM C. V. CHAPIN, SUPERINTENDENT OF HEALTH.

HEALTH DEPARTMENT,

OFFICE OF SUPERINTENDENT OF HEALTH,
CITY HALL, PROVIDENCE, R. I., Sept. 8, 1884.

SAMUEL M. GRAY, Esq., *City Engineer.*

Dear Sir, — A short time since you asked for an expression of my opinion in regard to the effects of the emanations from the Cove and rivers on the public health. I regret exceedingly that I cannot give you any figures in regard to this matter. All that I can do is to present the opinion of the medical profession and my own, and to state certain well-established hygienic principles. I contemplated at one time arranging upon maps the location of the deaths occurring in certain classes of diseases that might be especially affected by an impure atmosphere, but it would be a great deal of labor, and I am not provided with the assistance necessary to accomplish it. I believe that,

after all, such a set of charts would prove very little. In drawing conclusions upon this subject from the returns of deaths and sickness, it would be almost impossible to avoid all sources of error. Thus, large numbers of persons who dwell at a distance from the rivers, work for many hours each day in their immediate vicinity. Sickness among such would be reported from the residence and not from the place of business. Moreover, the sewer system and public water supply are taken advantage of to a greater extent near the rivers than at a distance from them, and the influence exerted by these improvements would be the opposite of that produced by an impure atmosphere. These and similar reasons render it almost impossible to *prove* anything one way or the other in regard to the results of the foul condition of the public water.

But while I can present no mathematical demonstration showing that the existing condition of the rivers is pernicious, yet there is no doubt whatever in my own mind that it is so, and that decidedly. The foul water may exert an injurious influence in two directions. It may affect health in a general way without producing any particular or specific diseases, or it may be an important factor in the production of such diseases.

I. In my own experience it has seemed perfectly evident that pure air is one of the most important elements in protection against, and recovery from, the majority of diseases. All the specific fevers, all pulmonary diseases, especially consumption, dysenteries, diarrhœas, and all forms of children's diseases, do far better the purer the air is that the patients are supplied with. This view is the universal one in the medical profession. It is the usual custom nowadays to give fever patients as much and as pure air as possible, and they are often cared for in tents or in light wooden barracks. Surgeons insist upon the necessity for pure air in all operations of moment, and of late years the cubic air space for each patient has been greatly increased in all the newer hospitals. Children and infants are peculiarly susceptible to atmospheric conditions, and it is probably chiefly to the impurity of the air that we find the rate of infant mortality in cities so high The children of both rich and poor improve wonderfully when sent from the city into the country; in the case of the former it can scarcely be adduced that their surroundings are better in the country, for in most summer resorts the majority of the guests find everything inferior to what they have at home, except the air.

It may be argued that the change for the better that is seen when the sick are sent from the city is due in part to the change *per se*, and not to the increased purity of the atmosphere. But there are numer-

I have received communications from some fifty physicians of the city upon this subject, and of forty-three who have a general practice which permits of their forming an opinion of value, thirty-three stated as their emphatic belief that the emanations from the rivers and Cove do produce a decidedly injurious effect upon the general health of the city, and they were strong in their condemnation of any policy which would allow the pollution to continue. The remainder saw no reason for thinking that the impure atmosphere could exert any injurious influence.

As regards the production of specific diseases, the majority were of the opinion that no such diseases could be traced to this source; while a few, and among them one or two of our leading physicians, stated that they were convinced that many cases of diphtheria, typhoid and malarial fevers were directly due to the state of the rivers and Cove.

In regard to the opinion of medical men and sanitarians in other places, as to the effect of the pollution of streams upon health, I would say that I have corresponded with the health authorities in many of our American cities, and in all where they have had any experience with this evil, they deem such pollution to be decidedly dangerous to the public health. They have repeatedly urged upon their city governments the necessity of abating the nuisance, and as you well know, several cities have spent large sums of money to remedy the evil. From your perusal of the reports of the Rivers' Pollution Commission, and other commissions in England, you are of course aware of the stand taken by health officers abroad upon this subject. They find from the nature of the case that it is well-nigh impossible to substantiate their views by means of figures, but they usually agree that the emanations from the foul streams are injurious to health.

From a careful study of the case in question and a consideration of the views of our own physicians and of health officers here and abroad, I have no hesitancy in saying that I consider that the foul condition of the rivers and Cove basin exerts an injurious influence on the general health, increasing the liability to disease and preventing recovery from it. Moreover, there is danger that these waters may become the source of certain specific diseases, especially Asiatic cholera, if it should reach us, as it possibly will.

As the present sources of pollution will increase rather than diminish, I think that setting all other reasons aside, the health of the city imperatively demands that steps shall be immediately taken to remedy the existing evil as soon as possible. One source of the river's pollu-

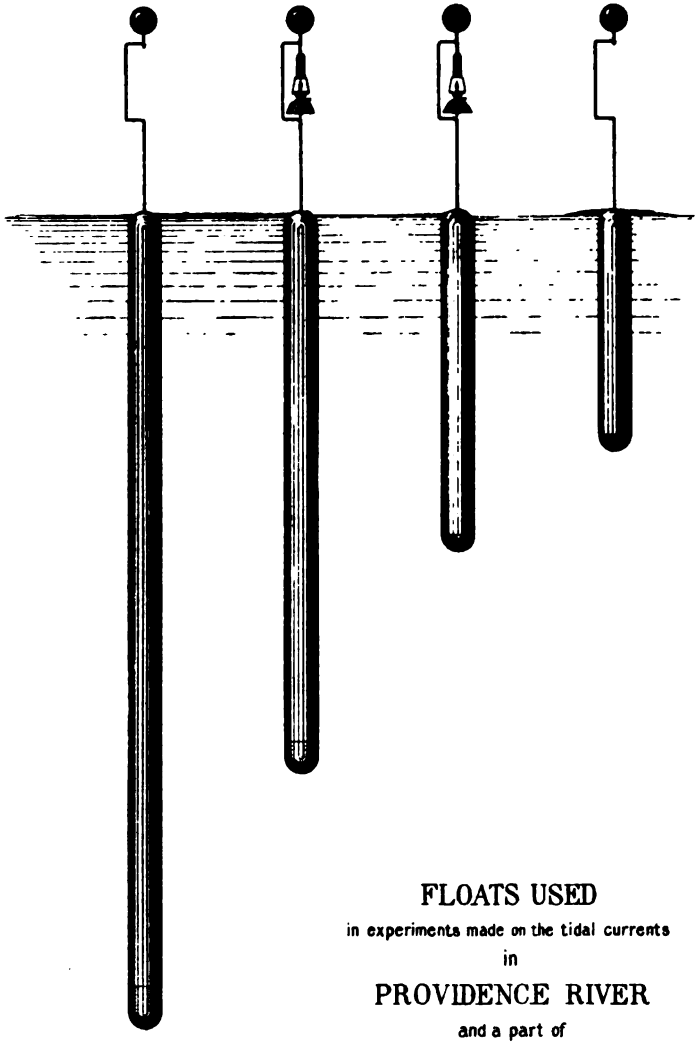
tion is the sewage of the city, and I hope that the expected report from you will recommend a plan for its successful disposal.

In regard to the pollution from other sources, necessity demands that the greatest care and diligence should be taken to secure equitable and efficient legislation, which must then be faithfully enforced.

Yours truly,

C. V. CHAPIN,
Supt. of Health.

PLATE XXII



FLOATS USED

in experiments made on the tidal currents

in

PROVIDENCE RIVER

and a part of

NARRAGANSETT BAY.

1883.

Scale 1/4

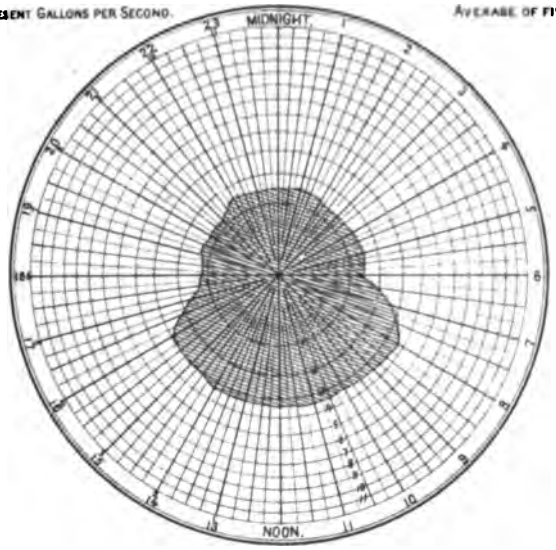
PLATE XXIV

SEWAGE FLOW.

PEARL STREET DISTRICT.

THE CIRCLES REPRESENT GALLONS PER SECOND.

AVERAGE OF FIVE DAYS.



ELM STREET DISTRICT.

AVERAGE OF THREE DAYS.

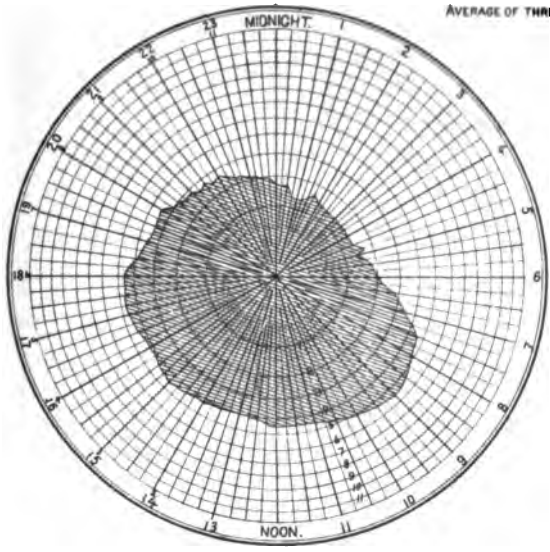


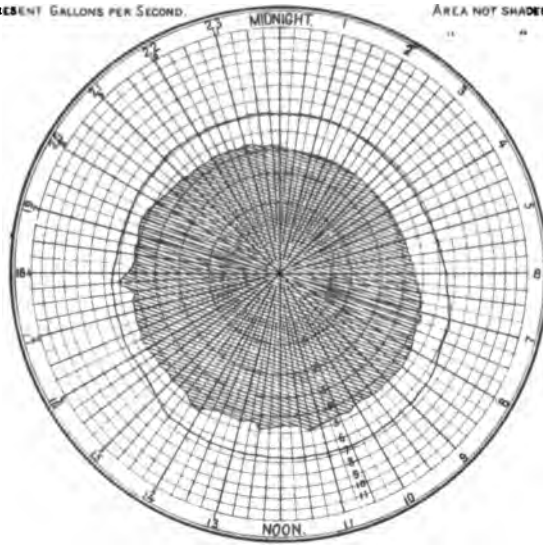
PLATE XXV.

SEWAGE FLOW.

BROOK STREET DISTRICT.

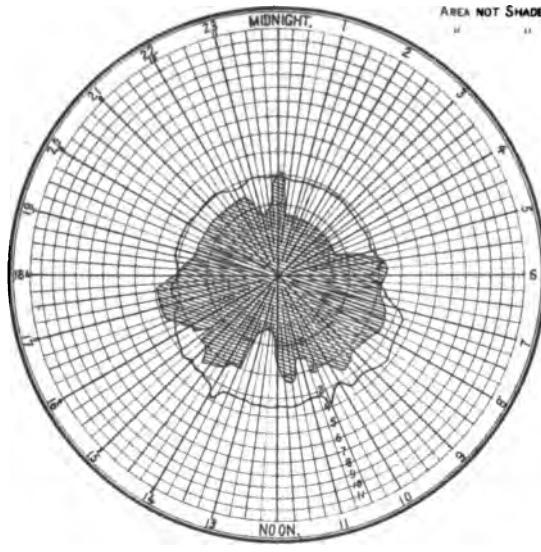
THE CIRCLES REPRESENT GALLONS PER SECOND.

AREA NOT SHADED, COLD WEATHER
" " WARM "



NORTH MAIN STREET DISTRICT.

AREA NOT SHADED, MONDAY.
" " FRIDAY



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Proposed plan for a sewerage system
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